Title
Ambient Vibration Study of Berkeley Civic Center

Authors
Gilani, Amir
Chavez, Juan
Blondet, J.

Publication Date
1995-10-01

AMBIENT VIBRATION STUDY OF BERKELEY CIVIC CENTER

by

Amir Gilani
Juan Chavez
Marcial Blondet

Report to the City of Berkeley

Department of Civil and Environmental Engineering
University of California
Berkeley, California

Report No. UCB/SEMM-95/12
Service to Industry
Project No. ES-2075

October 1995

AMBIENT VIBRATION STUDY OF BERKELEY CIVIC CENTER

ABSTRACT

This report summarizes the results of ambient vibration tests of the Berkeley Civic Center located at 2180 Milvia Ave. in Berkeley, California on October 1, 1995. Field measurements were recorded and analyzed to obtain natural vibration modes and frequencies of the building. These modal values would be useful in evaluating the seismic behavior of the building.

ACKNOWLEDGMENTS

This test program was conducted by the Department of Civil and Environmental Engineering of the University of California at Berkeley under Service to Industry Program Project No. ES-2075. The City of Berkeley sponsored the project. Professor James M. Kelly was the Principal Investigator.

The authors wish to express their gratitude to Ms. Arietta Chakos, the Assistant City Manager for the City of Berkeley, for her patience and assistance in facilitating the conduct of the tests. Chris Moy of the Department of Civil and Environmental Engineering provided invaluable help in the setup and testing of equipment and electronics. The assistance of Dr. Ian Aiken of the Earthquake Engineering Research Center in planning and coordination of this study is greatly appreciated.

1. INTRODUCTION

The seismic response of buildings depends on the modal parameters of the structure: natural frequencies, mode shapes, and modal damping. Field testing such as forced vibration, snap-back, and ambient vibration tests provide a reliable means of determining the dynamic properties of structures. Forced vibration tests, using mechanical vibration generators, have been successfully used to evaluate structural response at specified frequencies. Snap-back tests involve the pulling and release of structures. Ambient tests involve the measurement of structural response to on-site conditions.

Ambient tests measure small vibrations caused by factors such as wind, local traffic, and other movements in the building. Usually, ambient measurements are several times smaller than measurements from other types of field testing. Therefore, the structural properties measured during ambient tests are determined at relatively small response amplitudes. However, previous studies comparing forced vibration and ambient test data, demonstrate the viability of ambient test results [1 - 5]. The main advantages of ambient testing are the relatively low cost of tests, and the short time required for testing.

The objective of this study was to conduct ambient tests of the Berkeley Civic Center Building and to utilize the recorded measurements to compute the first few global mode shapes and natural frequency of the building in its three main directions (North-South, East-West, and Torsional). Additionally, it was decided to attempt to measure the in-plane vibration characteristics of the building roof.

2. BRIEF DESCRIPTION OF THE BUILDING

The Berkeley Civic Center Building is a five-story structure, with a basement and a small appendix on the roof. A typical floor has a "U" shape with the main body having dimensions of 171 ft. in the N-S direction and 50 ft. in the E-W direction. Each one of the "wings" of the "U" shape building has dimensions of 49 ft. in the N-S direction and 61 ft. in the E-W direction. The main entrances to the building are located at the first floor. The total height of the building is approximately 77 ft. Figure 1a shows the frontal view of the building; a typical floor plan of the building is shown in Figure 1b.

3. TEST SETUP

The response of the building to ambient excitations was measured with eight Kinemetrics SS1 Ranger seismometers. These are sensitive velocity transducers. The response of the sensors was amplified with Kinemetrics SC-1 Signal Conditioners. The velocity measurements were recorded with a Megadac portable data acquisition system and transferred to a PC-486 computer. In addition, frequency response of the sensors was monitored by an HP two-channel spectrum analyzer (model 3582A). The command center, including the recording and monitoring equipment, was set up on the third floor lobby, as seen in Figure 2a. Figure 2b shows two seismometers placed on the roof during one of the tests.

To determine the global mode shapes and frequencies of the building, measurements were taken at all the floors. At each floor, two instruments were placed in the E-W direction, as far apart as possible. That way, the sum of measurements of these sensors was dominated by the floor E-W translation, and the difference was dominated by the floor rotation. A similar arrangement was used to estimate the N-S translation response and to verify the torsional response. The addition and subtraction of the signals from the seismometers was done automatically in the Kinemetrics Model SC-1 Signal Conditioners.

A set of four sensors was placed on the roof for all the tests: sensors S1 and S2 in the E-W direction and sensors S3 and S4 in the N-S direction. The response of these instruments were used as a reference. A second group of four seismometers was moved from floor to floor, starting at the basement and ending at the fifth floor. Sensors S5 and S6 were located in the E-W direction and sensors S7 and S8 in the N-S direction. Due to the presence of floor carpeting, a large portion of the floor surfaces was not suitable for instrumentation. The E-W sensors (S5 and S6) were located in the waiting rooms, approximately 56 ft. apart, aligned with the center of the stairway towers. The N-S sensors (S7 and S8) were located on the center line of the building, placed approximately 20 ft. apart on the ends of floor lobbies. Figure 3 shows the arrangement of sensors on the roof and on a typical floor.

To characterize the in-plane motion of the building floors, all the seismometers were placed on the building roof. Three sensors in the E-W and one in the N-S direction were placed on the roof to monitor the response of the main body of the building. A pair of sensors, one in the E-W and one in the N-S direction, were placed at the end of the building wings to attempt to measure their local motions. Figure 4 shows the location of sensors during these tests.

4. TESTING PROCEDURE

Before starting the tests, the seismometers were calibrated by placing them side by side, oriented in the E-W direction, on the third floor lobby and recording their response. These measurements were used to establish relative calibration factors.

All velocity measurements from the seismometers were low-pass filtered at 100 Hz., and attenuated at 30 dB. The scanning rate was 200 Hz. Memory constraint of the Megadac data acquisition system limited each test to approximately two and half minutes of data recording. In order to ensure repeatability of measurements, a set of five tests was conducted for each sensor configuration. Velocity data was recorded in units of meters/second.

During each test, the response of all sensors was monitored on the PC screen to ensure that the data was adequate. Additionally, the frequency analyzer was used to visualize the frequency content of the measurements.

A clear signal was obtained from each seismometer at each floor. This indicated that the main response modes in the three principal building directions were adequately excited during the tests.

5. ANALYSIS OF EXPERIMENTAL DATA

The computer program MATLAB and its signal processing utilities [6] were used to process the experimental data. Each recorded data channel consisted of approximately 25,000 data points, recorded at a time interval of 0.005 second. Relative amplitude calibration factors between S1 and all the other seismometers were established from the initial calibration tests. The measurements were related by an approximately constant factor for a wide frequency range. These calibration factors were used to obtain consistent spectral amplitudes. Fourier spectra were obtained using Hanning windows of 4096 data points. Samples had a duration of 20.48 seconds and overlapped by 1000 points. Thus, the frequency resolution was approximately 0.05 Hz.

The Fourier spectra peaks of velocity measurements were computed for individual tests and averaged for each floor. Figures 5 - 10 show the amplitude and phase angle of Fourier transformations of individual floors in the three main directions.

It was decided to attempt to estimate the first two natural modes and frequencies in each direction (East-West, North-South, and Torsional). The modal frequencies occur at the significant peaks in the spectra. These main frequencies appeared consistently in the spectral response at all levels. The corresponding mode shapes were estimated from the transfer functions between each floor and the roof. The normalized modal amplitude is the amplitude of the transfer functions at each resonant frequency. The direction of the mode shape was determined from the phase angle between the floor and roof.

The response spectra calculated for each test are included in the Appendix.

6. MODAL PROPERTIES OF THE BUILDING

The calculated modal properties of the building are summarized below. Even though the level of excitation, and thus the measured response, was relatively small during testing, the frequencies and modes obtained are representative of the building dynamic characteristics.

a) Global Modes and Frequencies

The fundamental (first) translational frequencies of the building were found to be 2.3 Hz. in the E-W direction, and 2.4 Hz. in the N-S direction. The torsional frequency was estimated at 3.0 Hz. The calculated fundamental mode shapes were in-phase for all floors, consistent with the first mode behavior. Examining the spectrum transformations, it is seen that the E-W fundamental frequency is also present in the torsional spectra. Therefore, the fundamental torsion mode includes some translational component.

While the fundamental frequencies and mode shapes were determined accurately, the second vibration frequencies and their corresponding mode shapes could not be calculated as readily. The estimated second modal frequencies are 5.9 Hz. for the E-W direction, 7.0 Hz. for the N-S direction, and 8.5 Hz. for the torsional direction. The computed second mode shapes were consistent with typical building mode response, with the roof and 5th floor out of phase with the remaining floors, and maximum modal amplitudes observed close to the mid-height of the building. There are some uncertainties regarding these modal values because additional spectral peaks are observed at lower frequencies. The shapes corresponding to these intermediate frequencies are, however, all in phase, indicating a "first mode" type of response. It seems that these frequencies and modes could correspond to in-plane local floor responses.

Table 4 lists the computed modal values, and qualitative plots of the mode shapes are depicted in Figure 11.

b) In-Plane Roof Response

Unfortunately, an air-conditioning unit located at the roof of the building, near seismometers S5 and S7, was on intermittently throughout the testing. This unit controlled room temperature of computer units and thus could not be turned off. Therefore, seismometers S5 and S7 were saturated during most of these tests. This prevented calculation of any in-plane mode shapes. Figure 12 shows the frequency amplitude of the remaining six seismometers, averaged over five tests. It appears that the in-plane frequency of vibration of the roof is 4.9 Hz., which corresponds to in-plane bending of the floor diaphragm. This frequency was also present in some of the global spectra, with modal amplitude increasing along the height.

7. REFERENCES

[1] Trifunac, M., "Ambient Vibration Test of a Thirty-Nine Story Steel Frame Building," Report EERL 70-02, California Institute of Technology, Pasadena, California, 1970.

[2] Pardoen, G., "Imperial County Services Building, Ambient Vibration Test Results", Department of Civil Engineering, University of Canterbury, New Zealand, December 1979.

[3] Midorikawa, S., "Ambient Vibration Tests of Buildings in Santiago and Vina del Mar," Pontificia Universidad Catolica de Chile, January 1990.

[4] Stephen, R., "Ambient Vibration Study of Channing House," Department of Civil Engineering, University of California, Berkeley, California, August 1991.

[5] ANCO Engineers, Inc., "Forced Vibration Testing of the Oakland City Hall Building", April 1990.

[6] Krauss, T.P., Shure, L., and Little, J.N., "Signal Processing TOOLBOX for Use with MATLAB," The MATHWORKS Inc., Natick, Mass., February 1995.

TABLE 1. Recorded channels for global motion

Channel No.	*Instrument*	*Floor*	*Direction*
1	S1+S2	roof (reference)	E-W translation
2	S1-S2	roof (reference)	Torsional
3	S3+S4	roof (reference)	N-S translation
4	S3-S4	roof (reference)	Torsional
5	S5+S6	typical floor	E-W translation
6	S5-S6	typical floor	Torsional
7	S7+S8	typical floor	N-S translation
8	S7-S8	typical floor	Torsional

TABLE 2. Location of sensors during in-plane measurements

Channel No.	*Instrument*	*Floor*	*Direction*
1	S1	roof	E-W
2	S2	roof	E-W
3	S3	roof	E-W
4	S4	roof	N-S
5	S5	roof	E-W
6	S6	roof	E-W
7	S7	roof	N-S
8	S8	roof	N-S

TABLE 3. Ambient test log

Test No.	*Sensor Locations*	*Comments*
01-02	3rd floor	calibration
03-07	roof & basement	global motion
08-12	roof & 1st floor	
13-17	roof & 2nd floor	
18-22	roof & 3rd floor	
23-27	roof & 4th floor	
28-32	roof & 5th floor	
33-37	roof	in-plane motion

TABLE 4: Modal amplitudes for global mode shapes

	East-West		North-South		Torsion	
frequency / floor	f_1 =2.3 Hz	f_2 =5.9 Hz	f_1 =2.4 Hz	f_2 =7.0 Hz	f_1 =3.0 Hz	f_2 =8.5 Hz
roof	1.00	1.00	1.00	1.00	1.00	1.00
fifth	1.51	0.88	0.89	0.35	1.32	0.45
fourth	1.22	-1.70	0.72	-0.78	1.15	-1.78
third	0.90	-1.83	0.53	-1.24	0.94	-1.31
second	0.49	-1.56	0.30	-0.88	0.48	-0.90
first	0.15	-0.40	0.105	-0.39	0.16	-0.57
base	------	-------	-------	--------	--------	--------

Figure 1a: Front View of Berkeley Civic Center

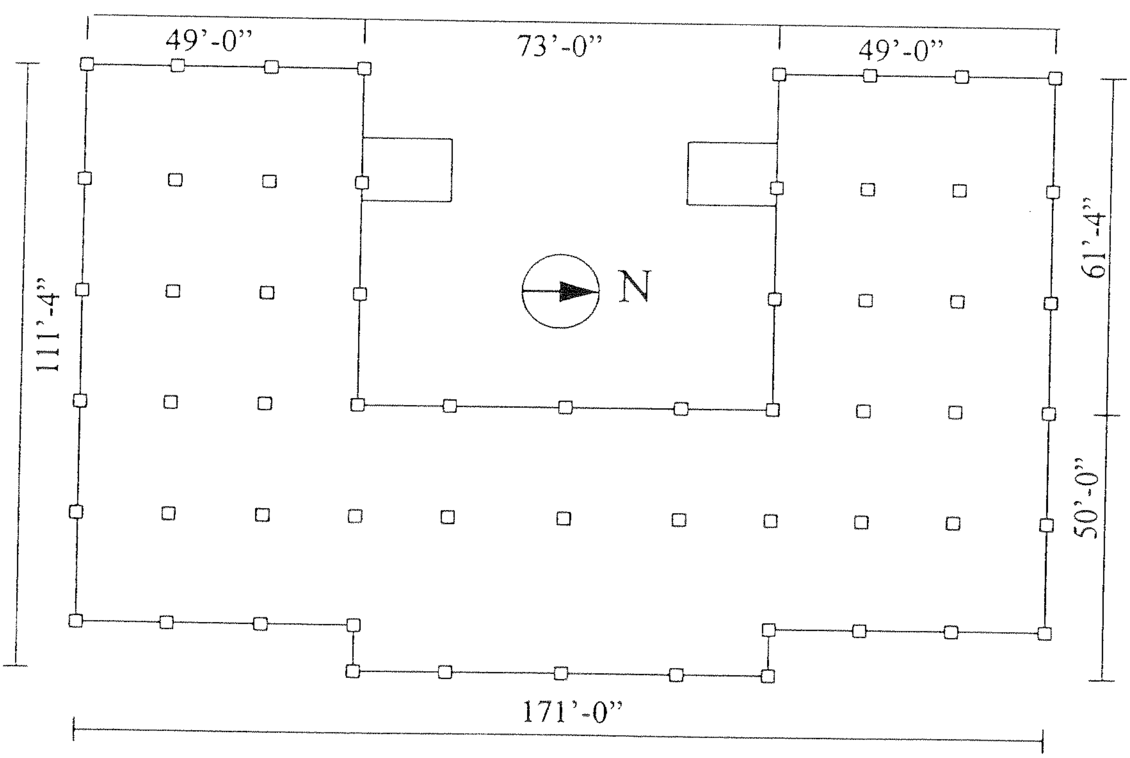


Figure 1b: Typical Floor Plan

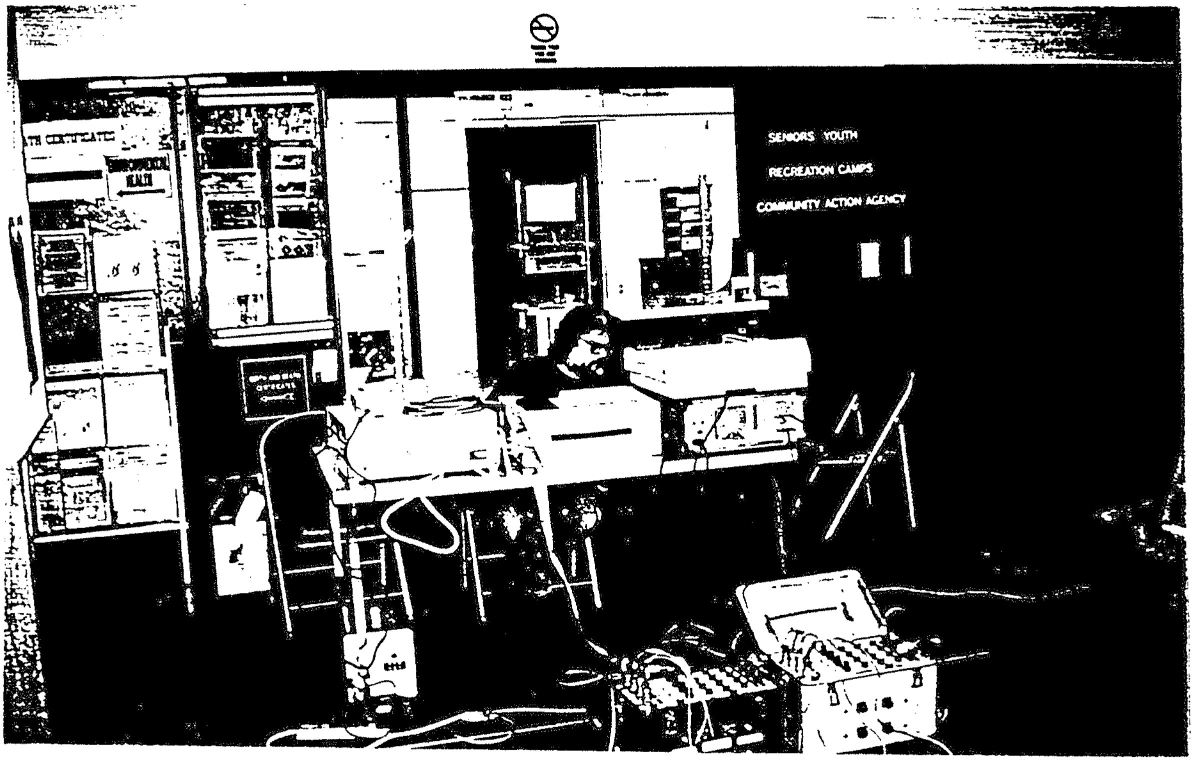


Figure 2a: Command Center, Third Floor Lobby

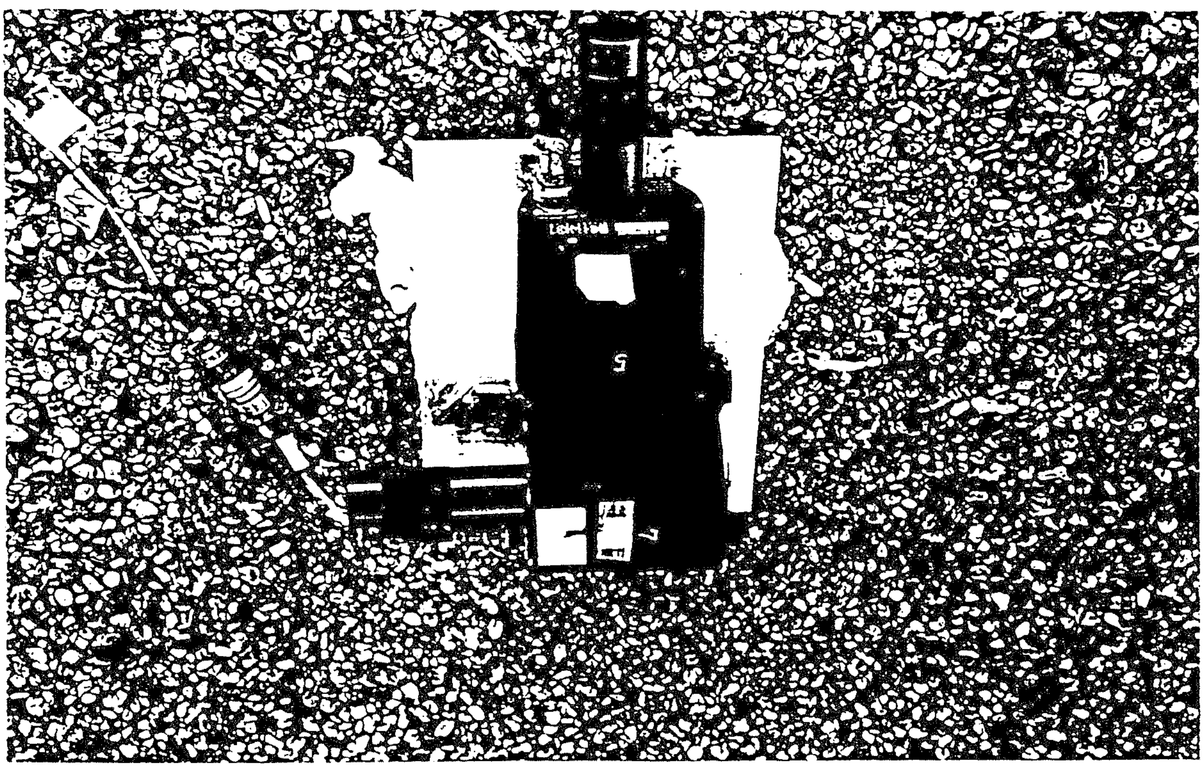


Figure 2b: Seismometers S5 and S7, Located on the Roof

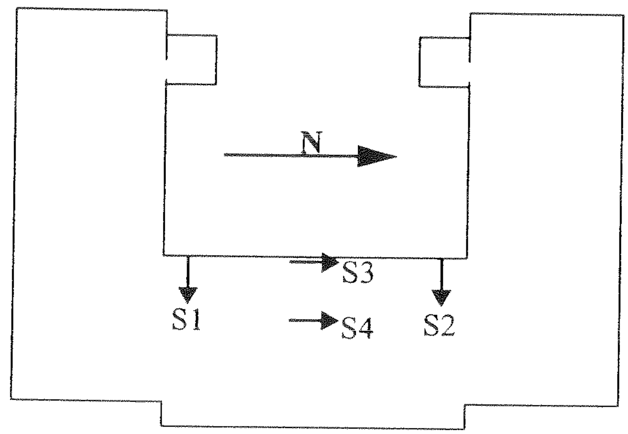


Figure 3a: Seismometers Located on the Roof, Global Motion

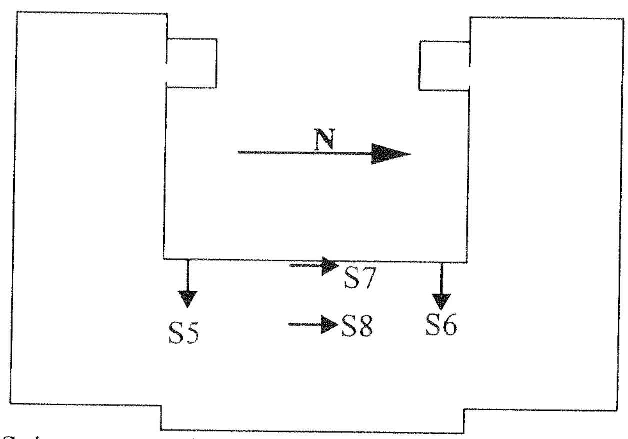


Figure 3b: Seismometers Located on a Typical Floor, Global Motion

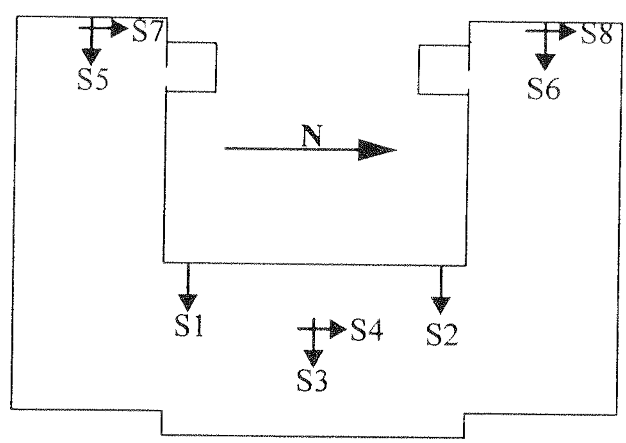


Figure 4: Seismometers Located on the Roof, In-Plane Motion

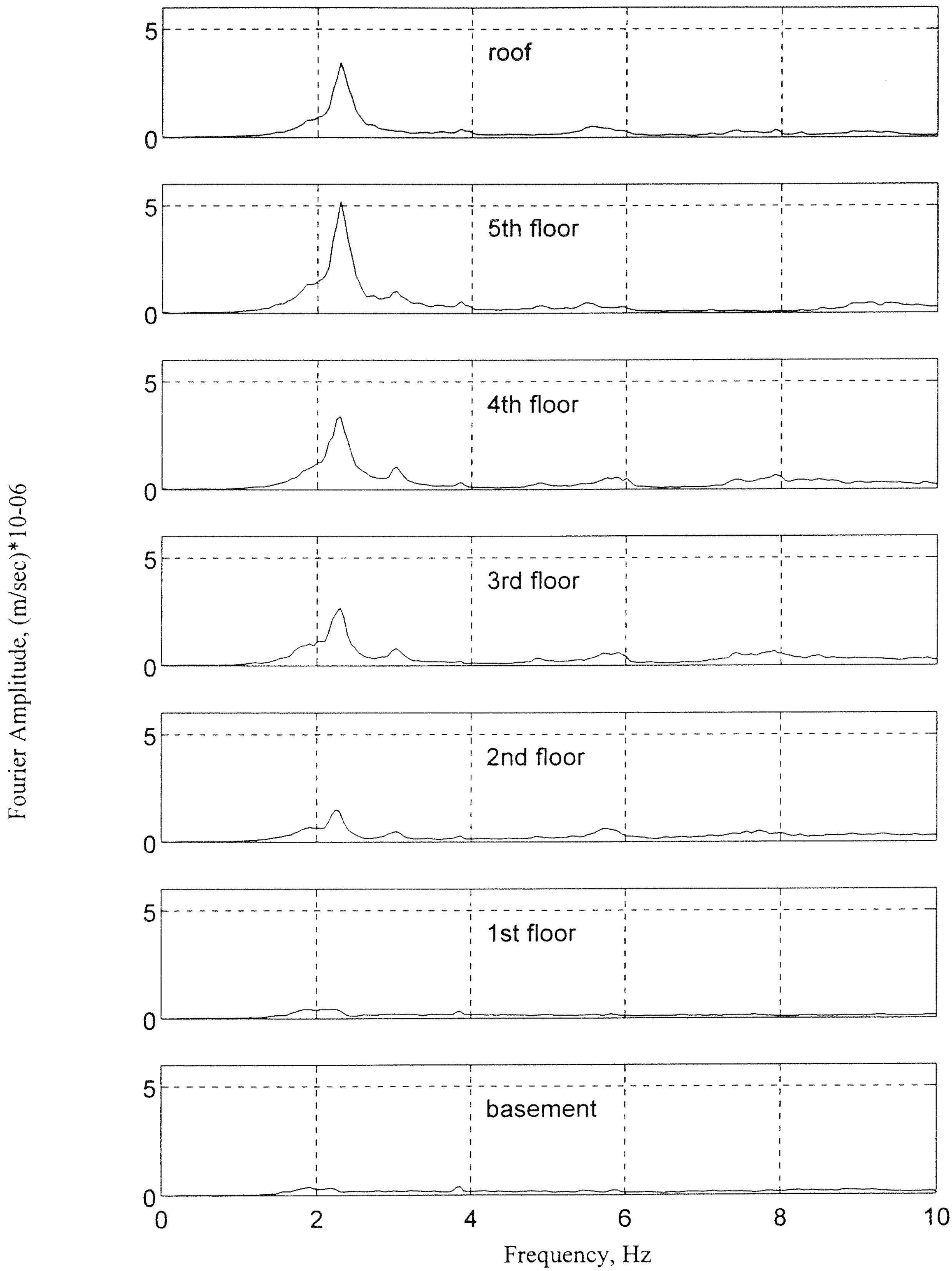


Figure 5: Amplitude of Frequency Response, East-West Direction

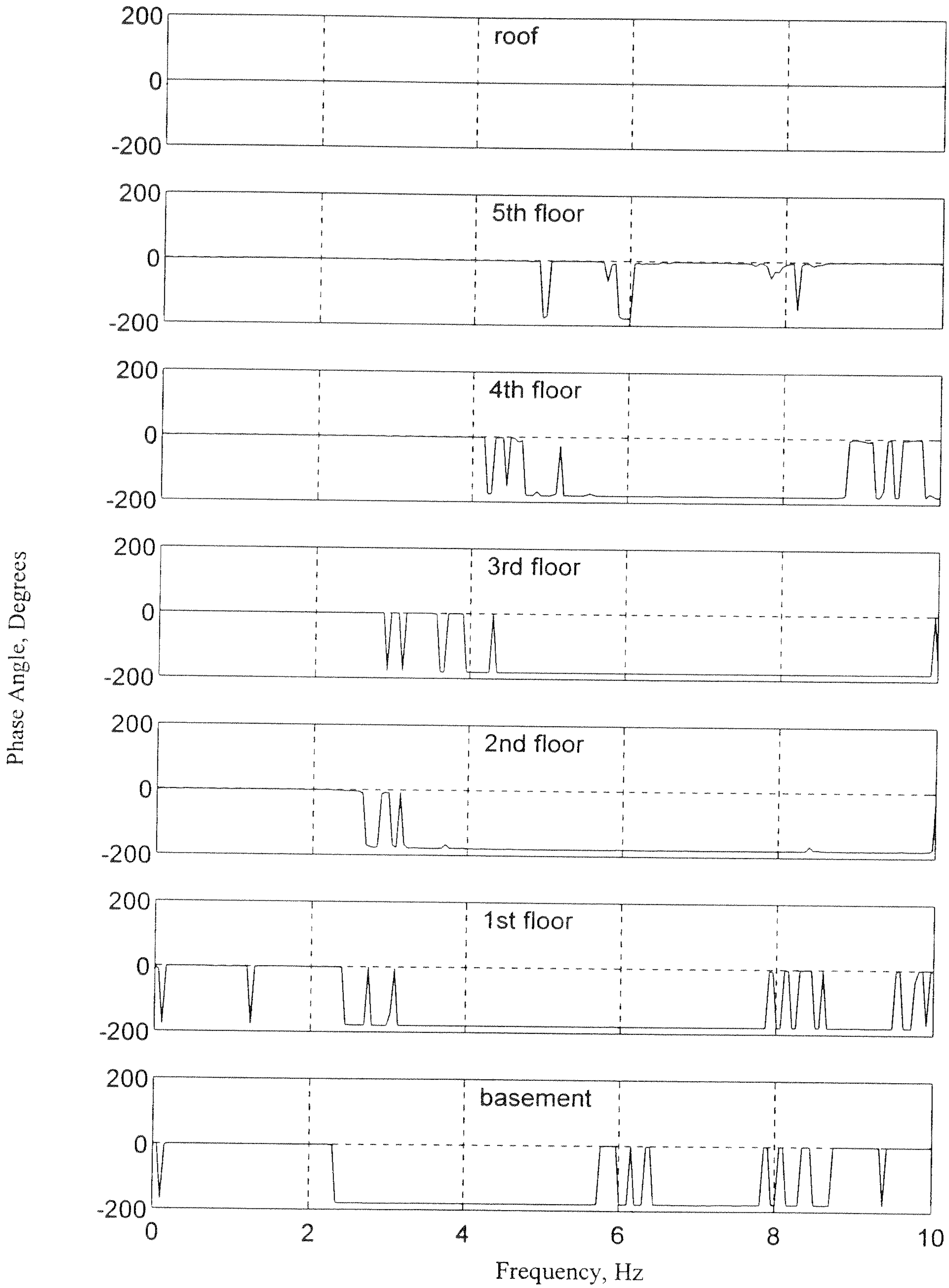


Figure 6: Phase Angle of Frequency Response, East-West Direction

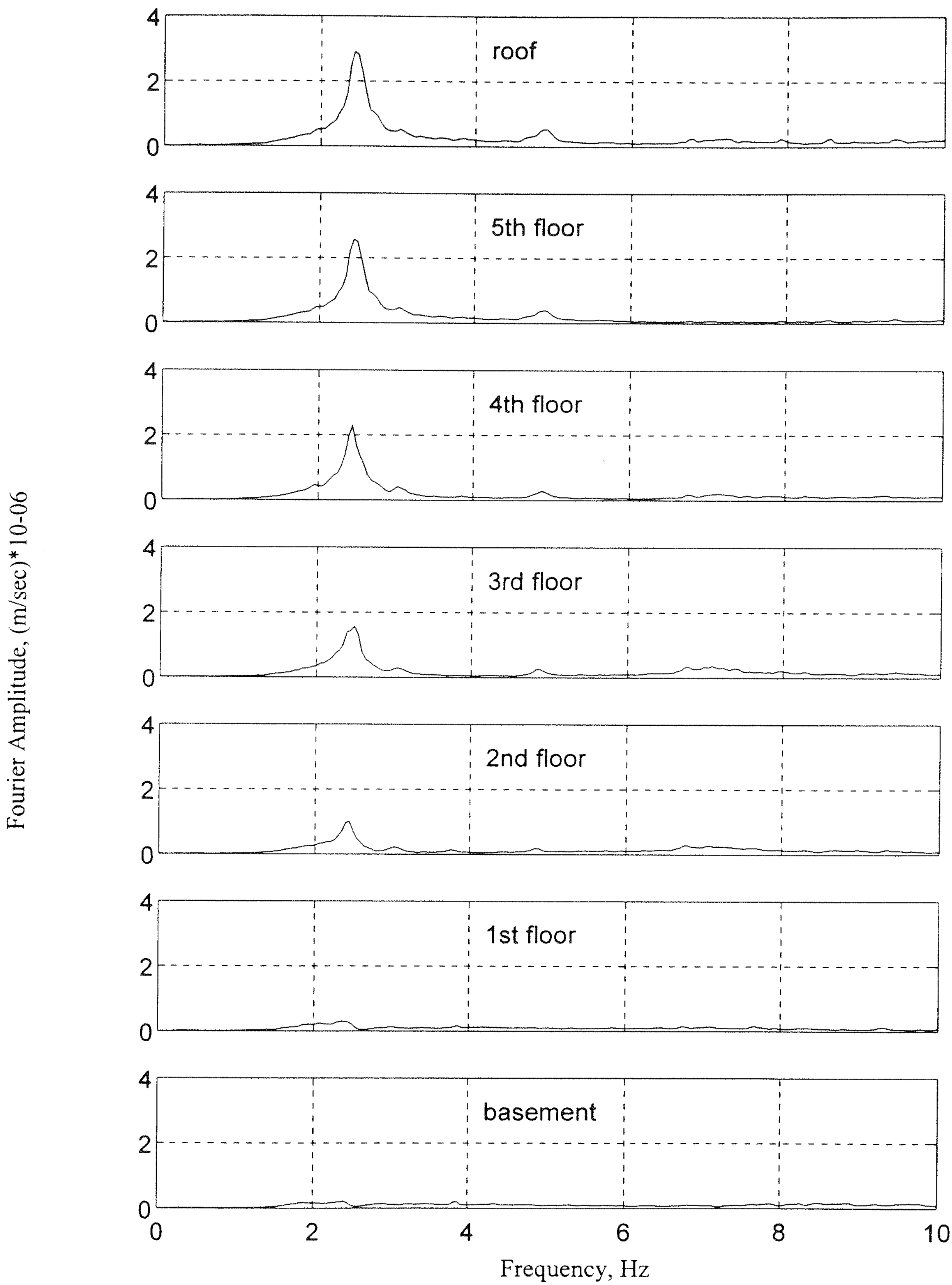


Figure 7: Amplitude of Frequency Response, North-South Direction

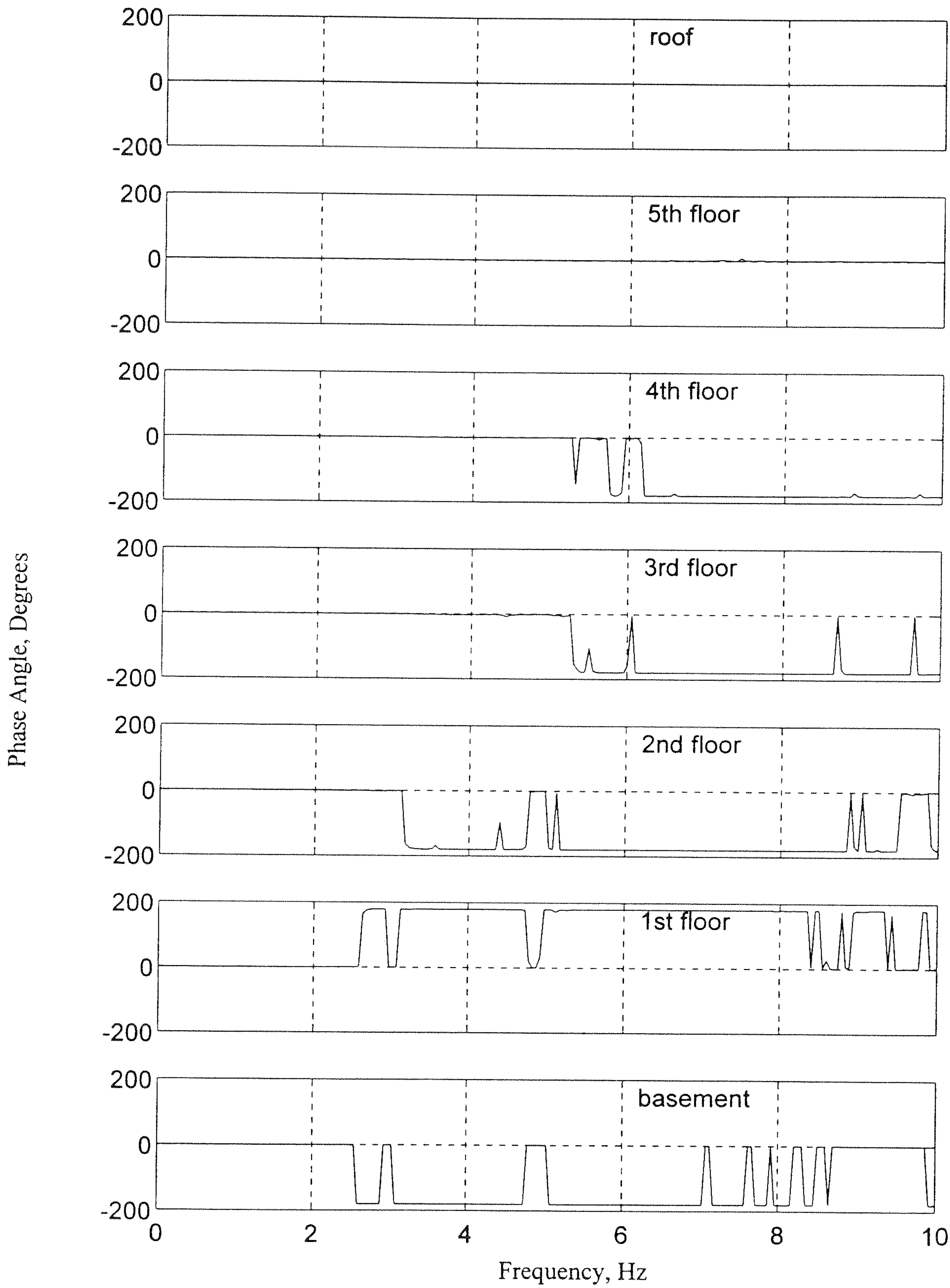


Figure 8: Phase Angle of Frequency Response, North-South Direction

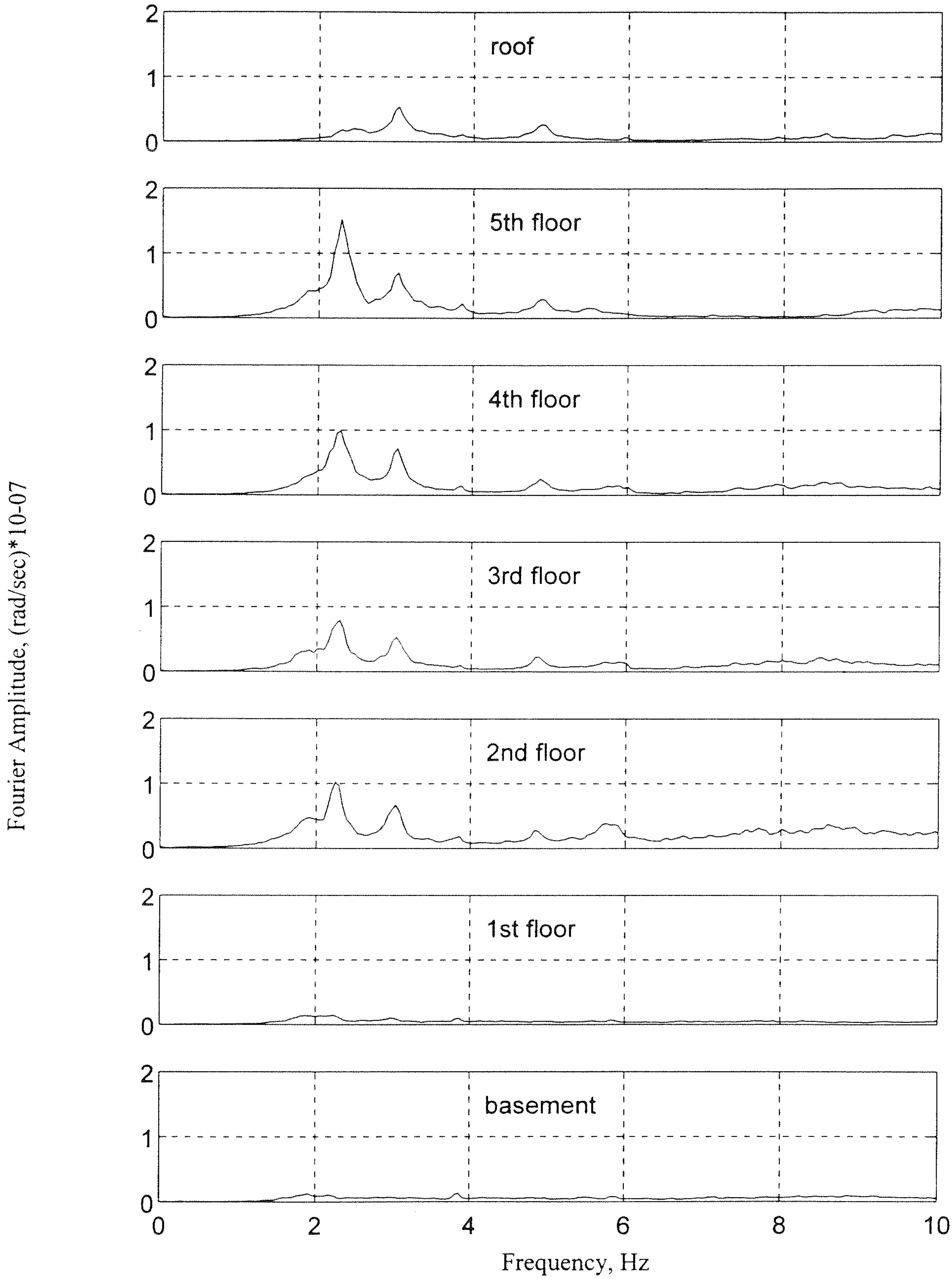


Figure 9: Amplitude of Frequency Response, Torsion

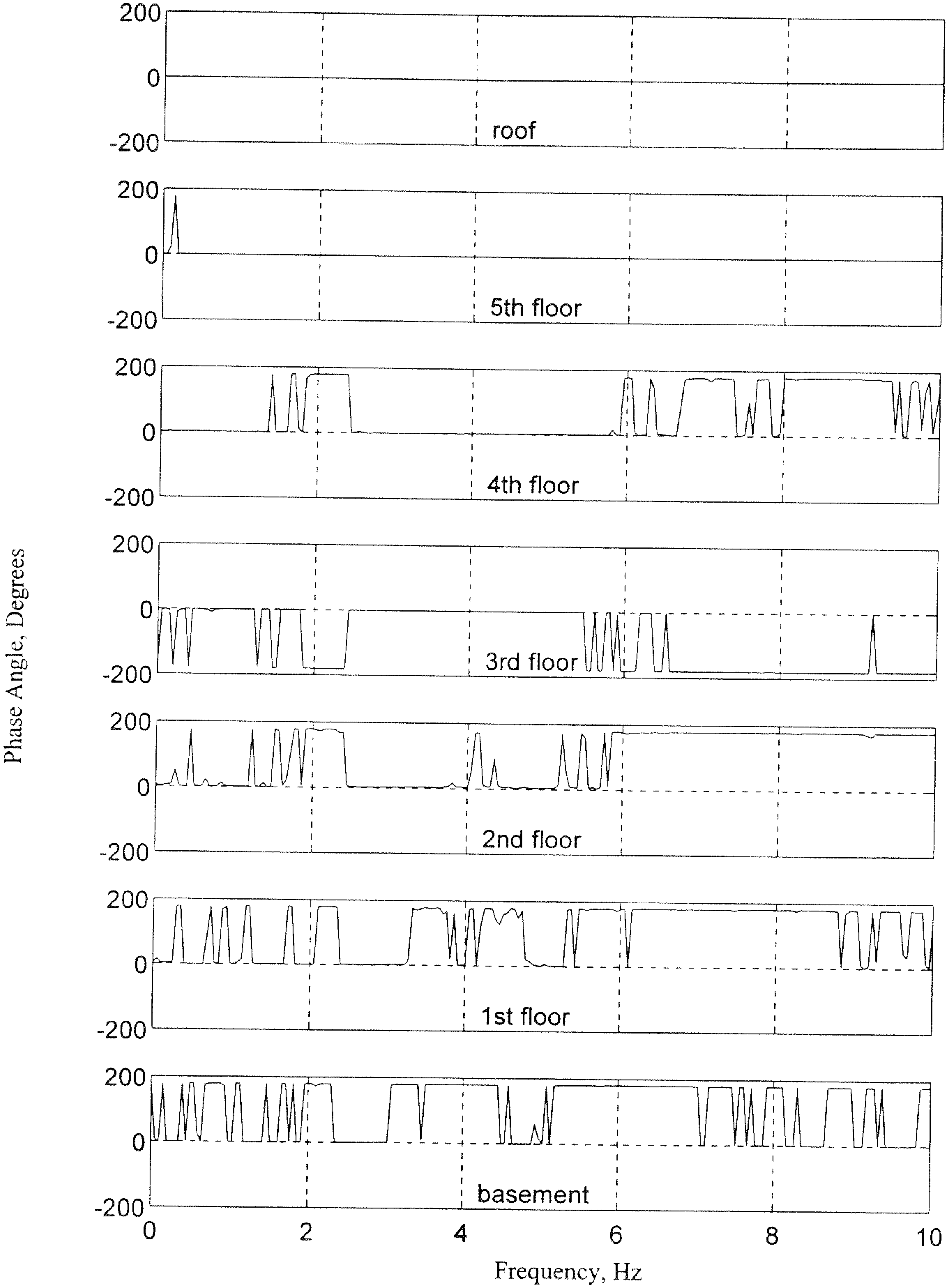


Figure 10: Phase Angle of Frequency Response, Torsion

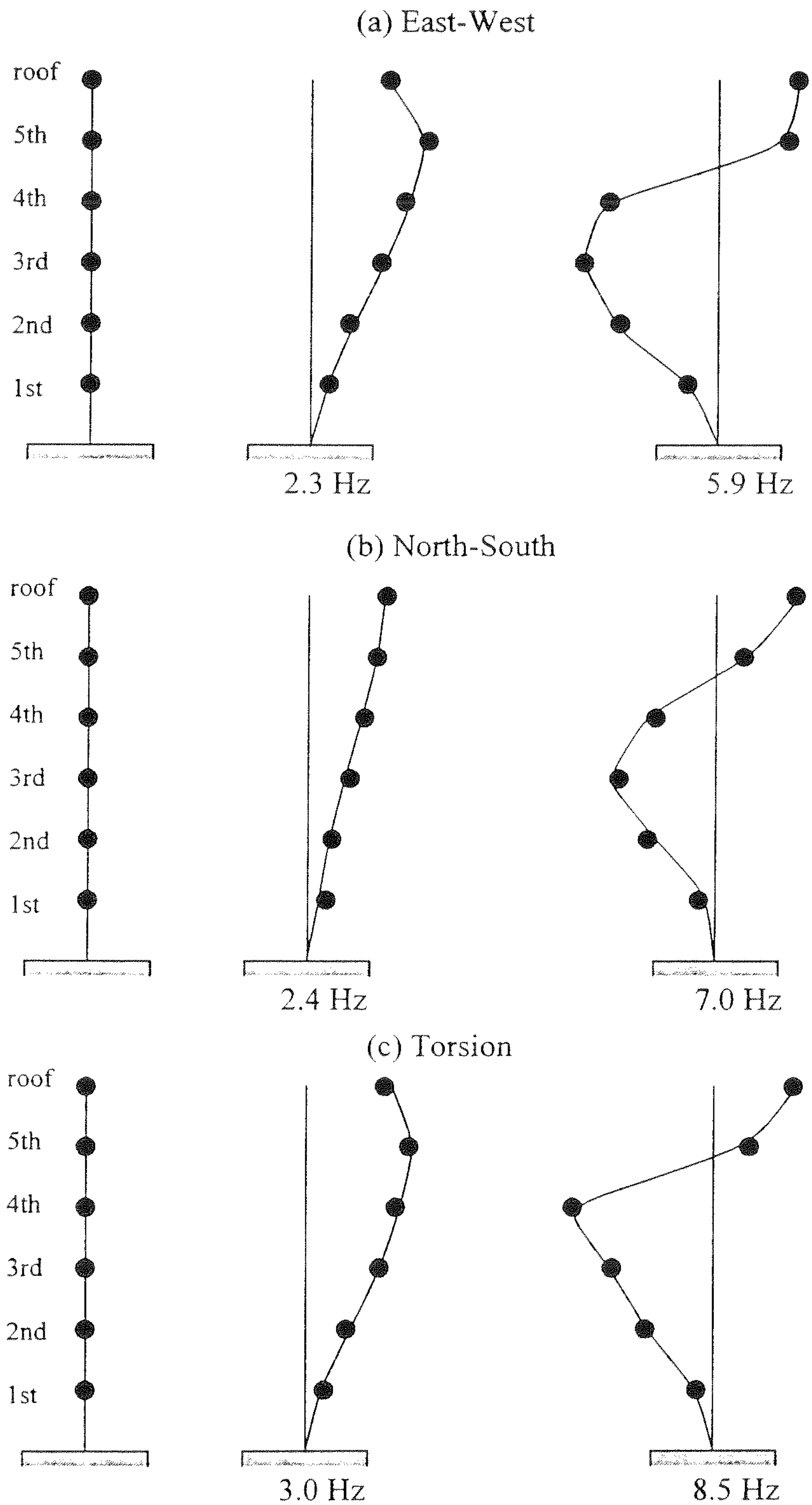


Figure 11: Vertical Mode Shapes

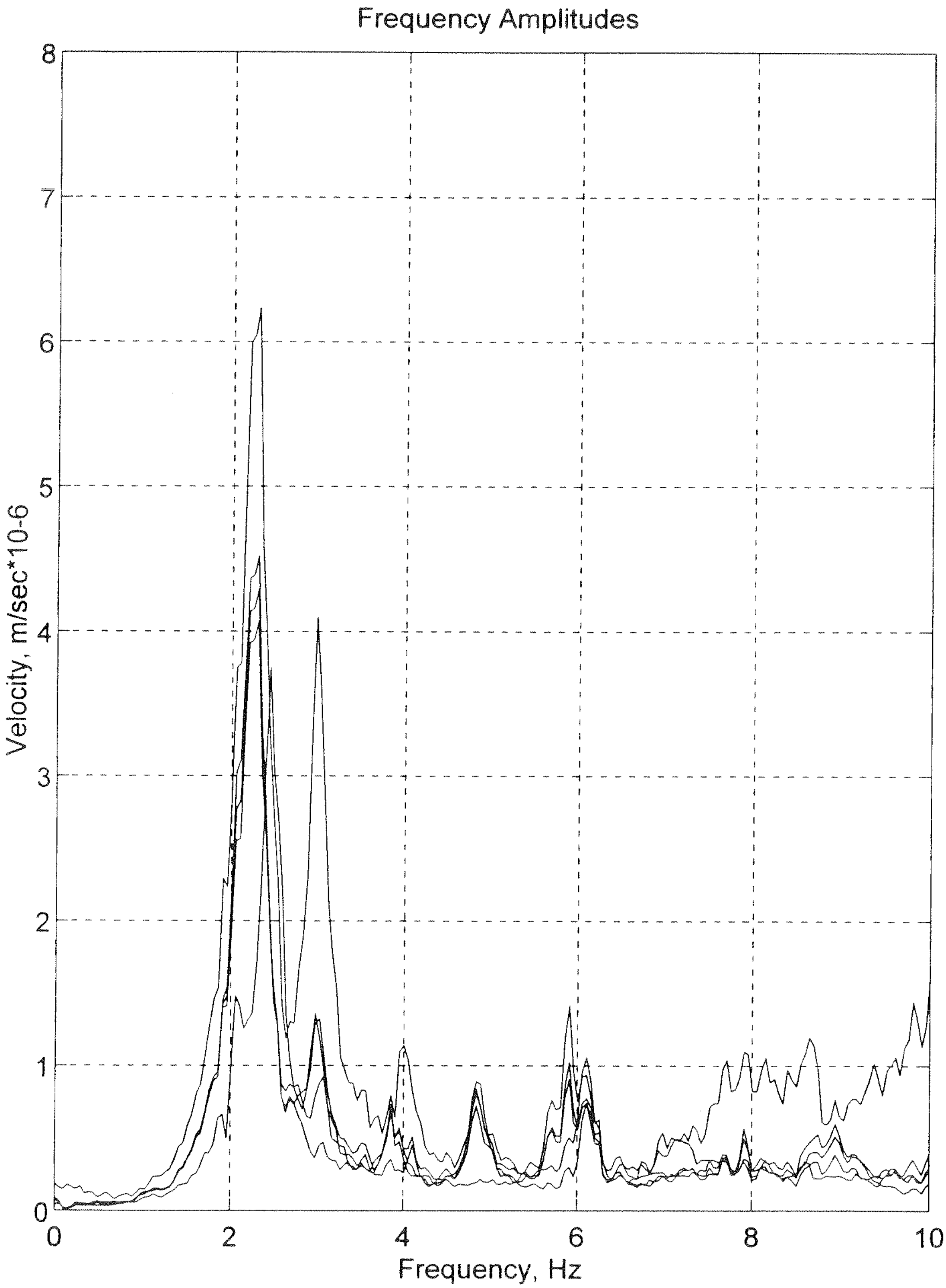
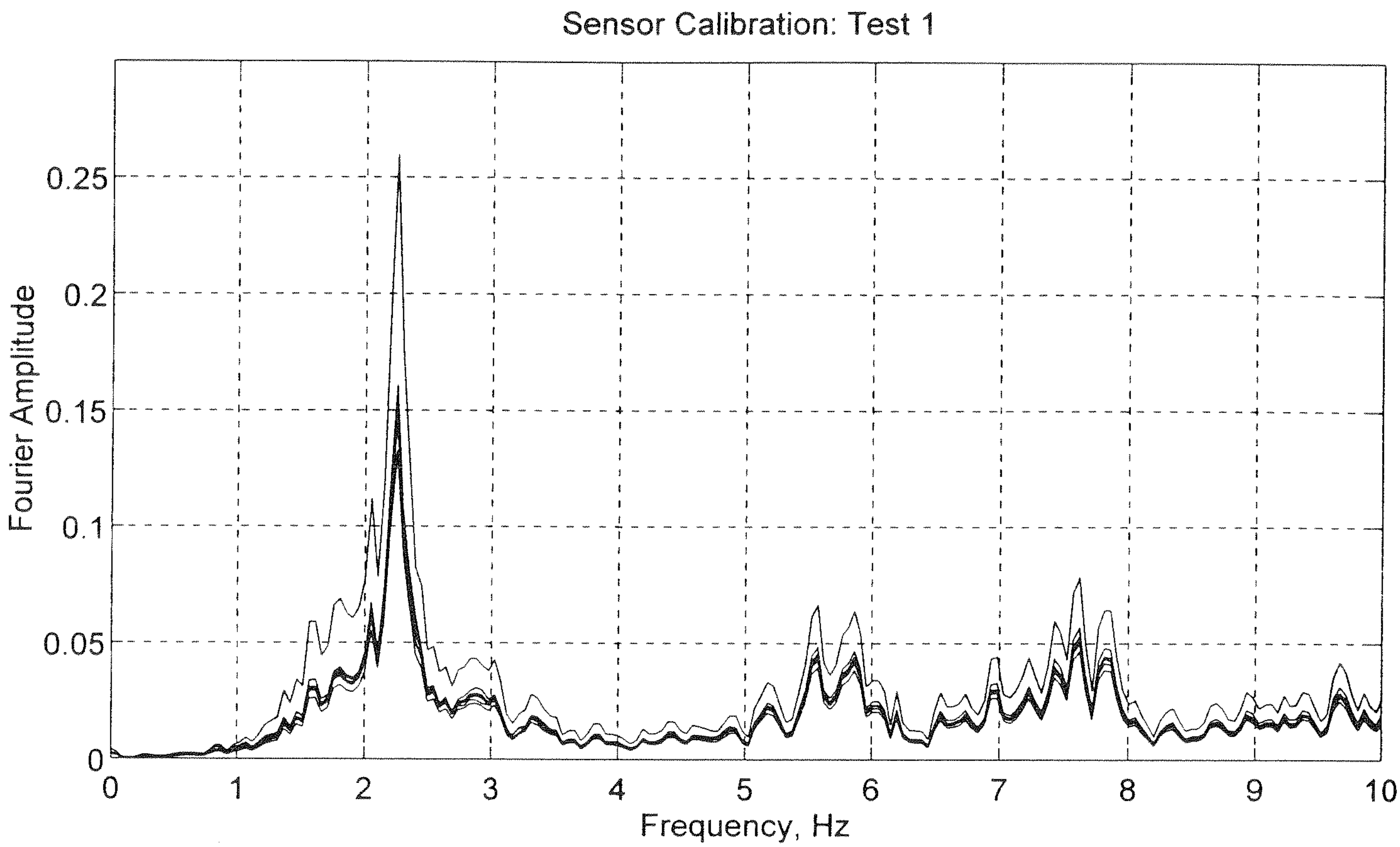


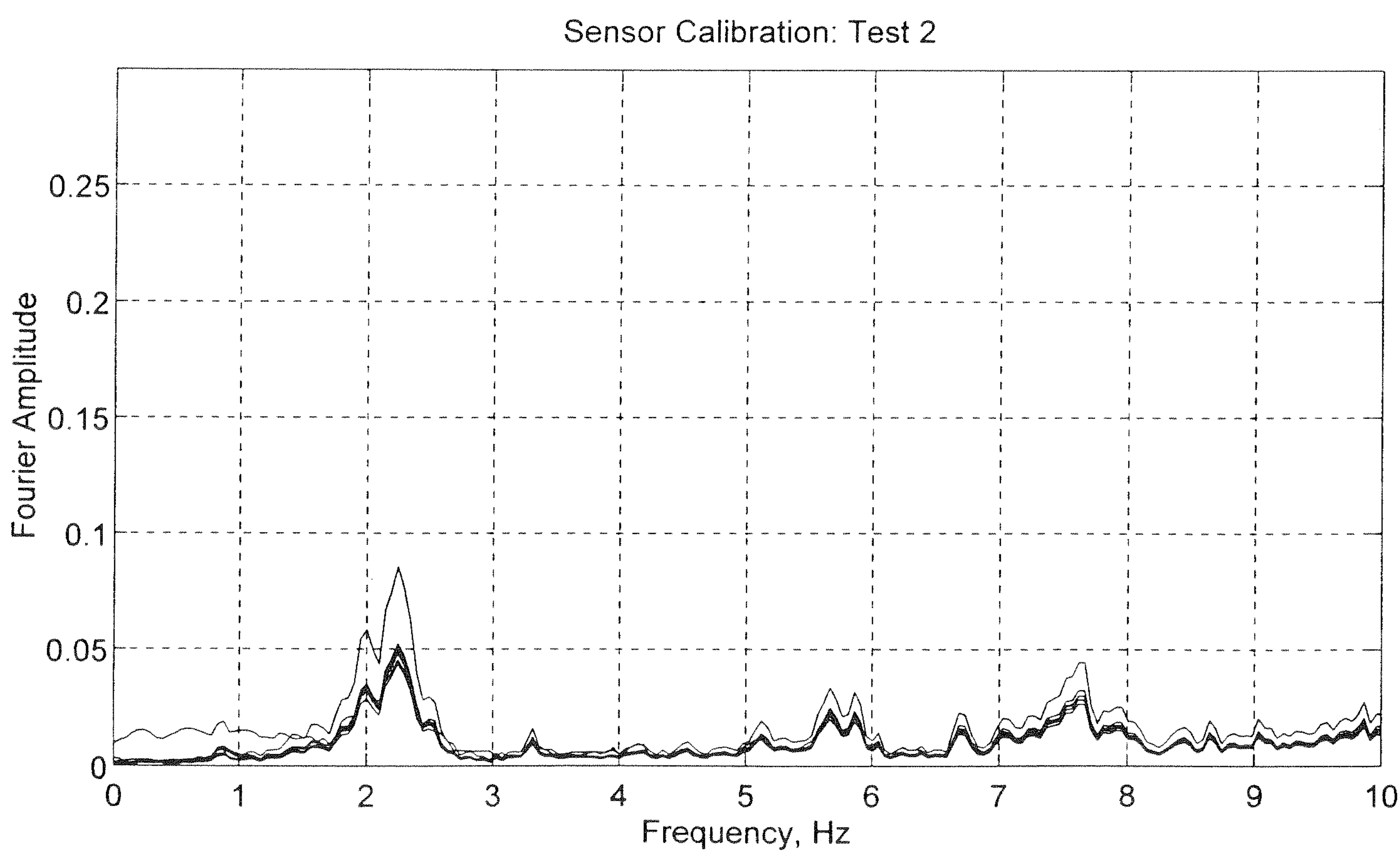
Figure 12: Amplitude of Frequency Response, Roof In-Plane Motion

APPENDIX

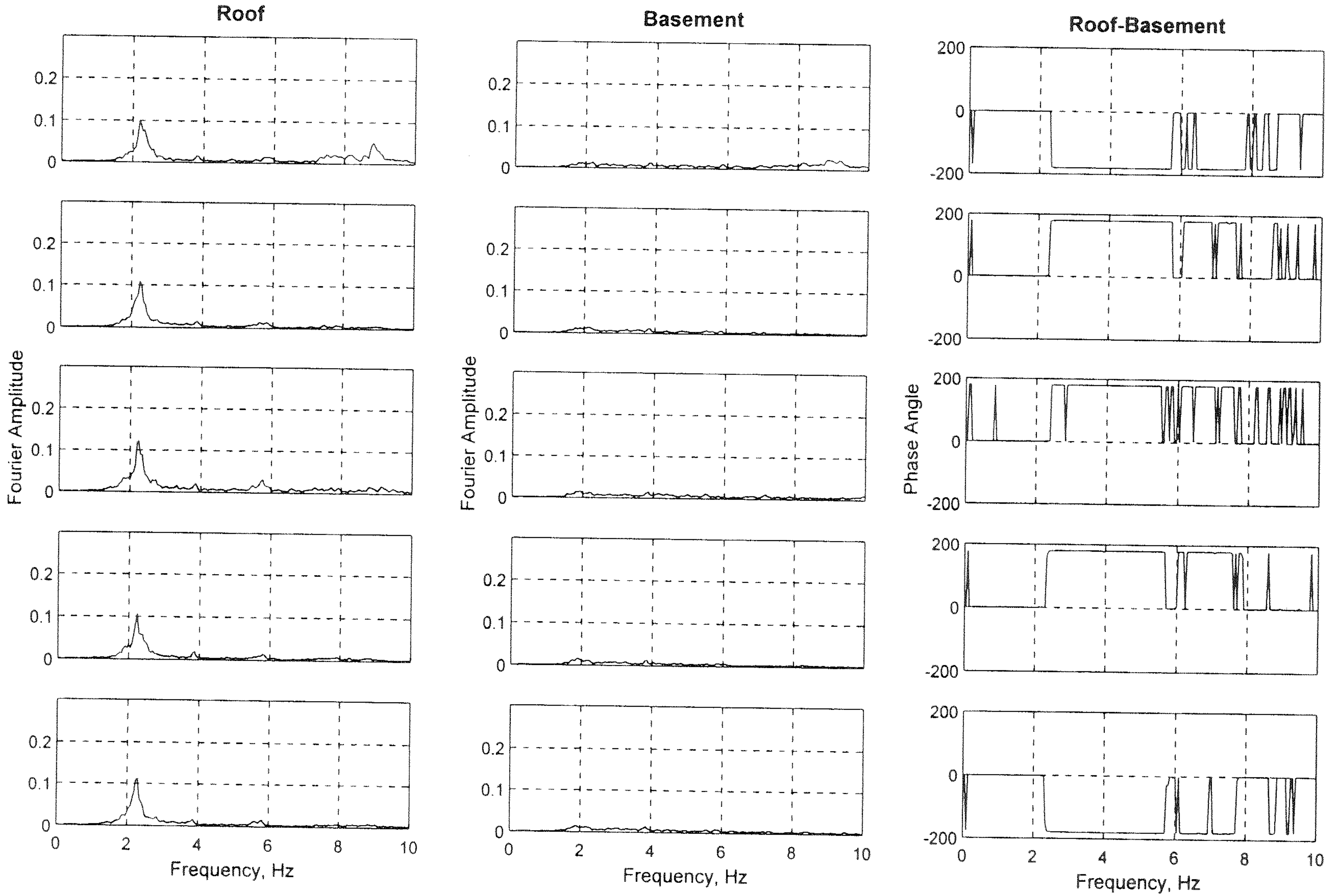
This appendix presents a summary of the computed Fourier spectra for all the tests.

The first two figures show the amplitude of all the sensors during the two calibration tests. Fourier spectra of each floor response in the three directions follow. Finally, the spectra for individual channels during in-plane testing are presented.

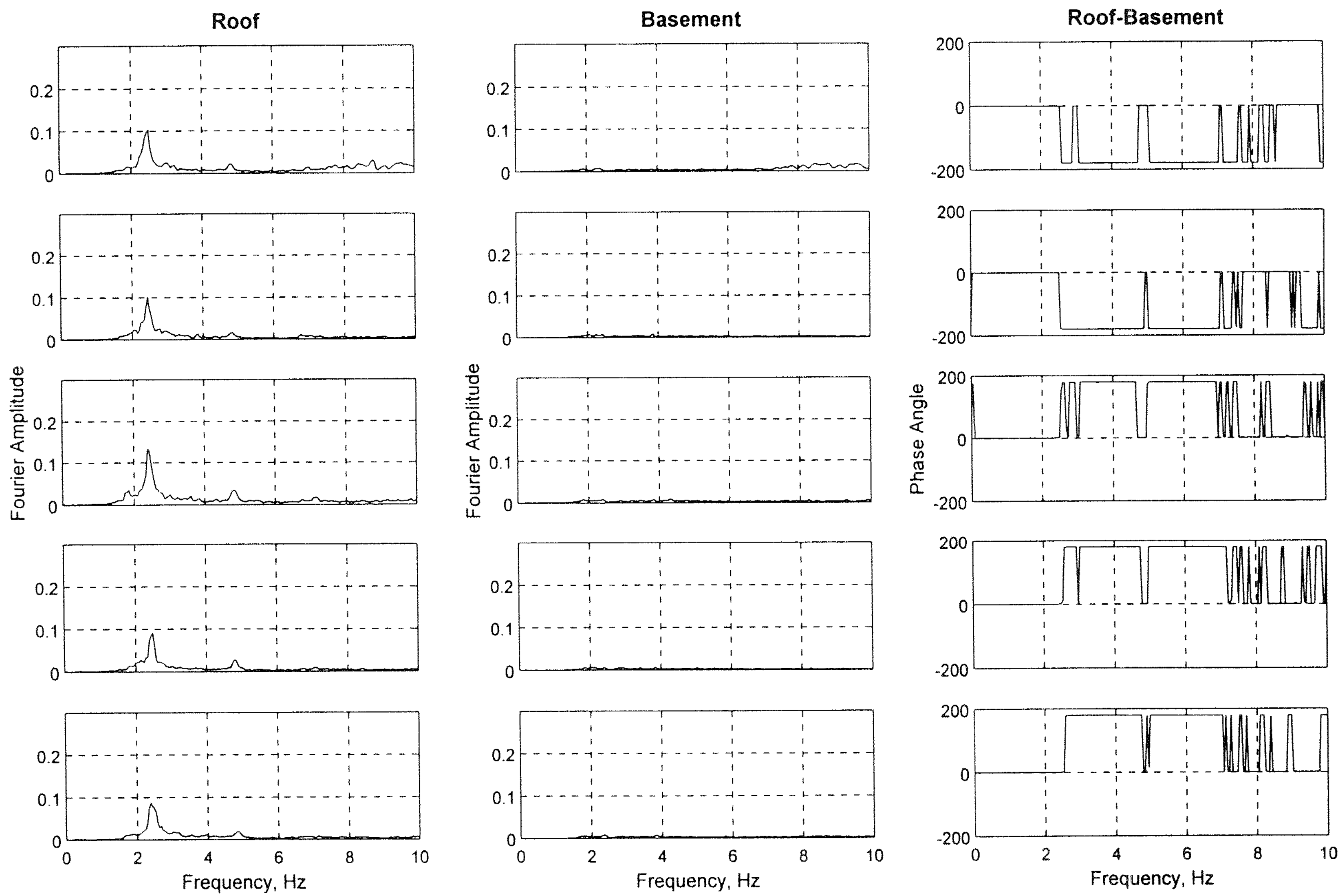

Sensor Calibration: Test 1
Fourier Amplitude
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
Frequency, Hz

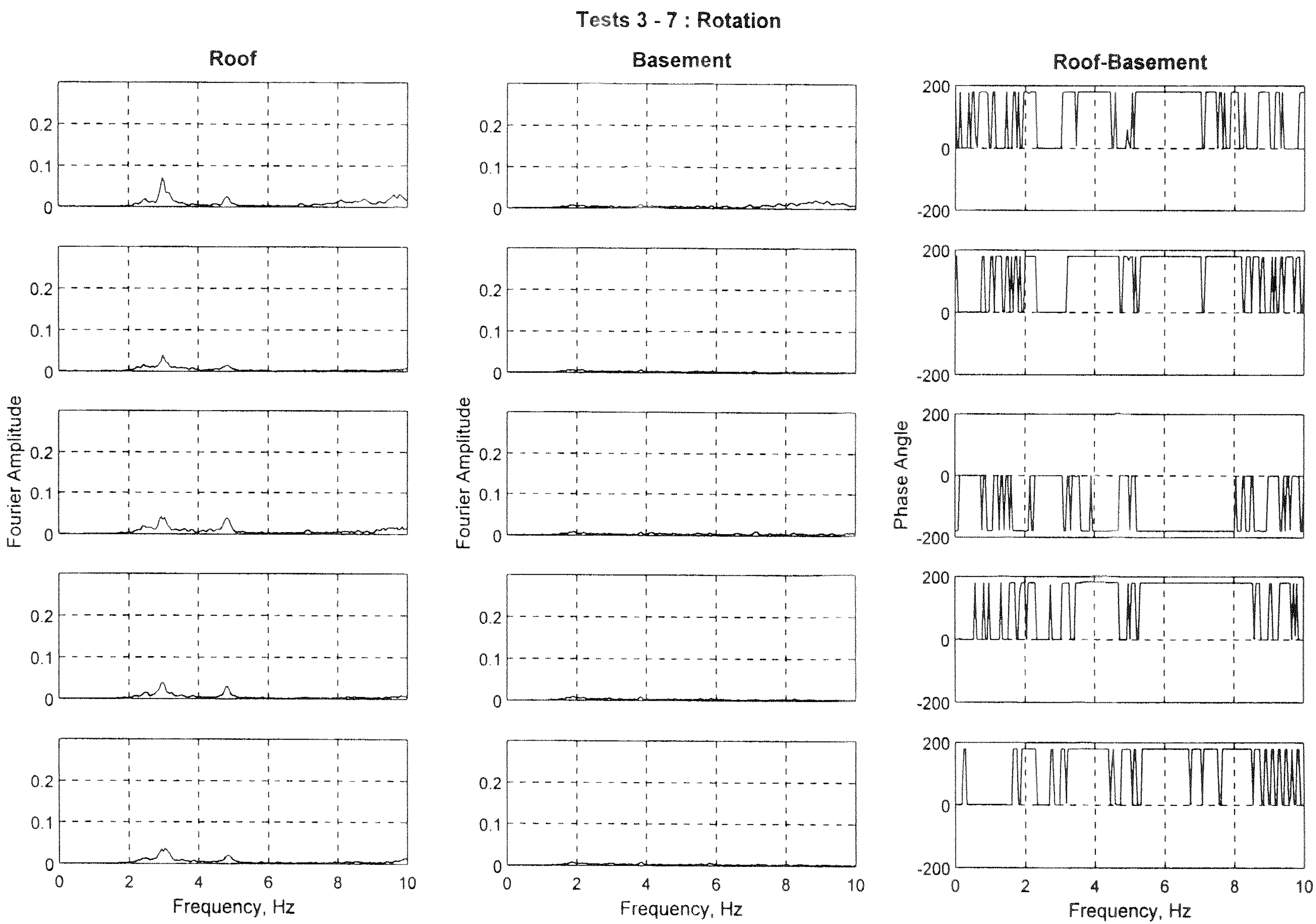

Sensor Calibration: Test 2
Fourier Amplitude
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10
Frequency, Hz

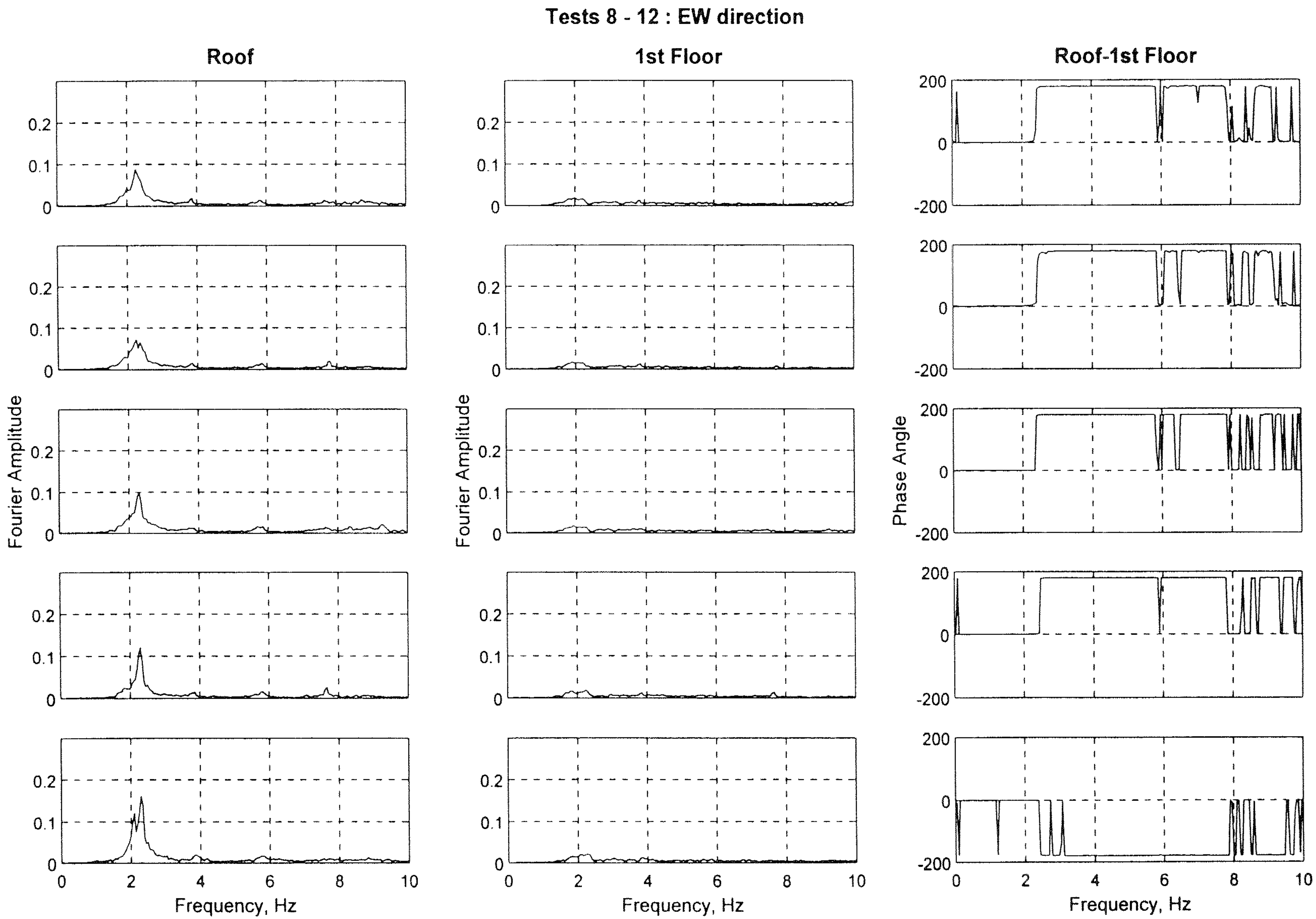
Tests 3 - 7 : EW direction

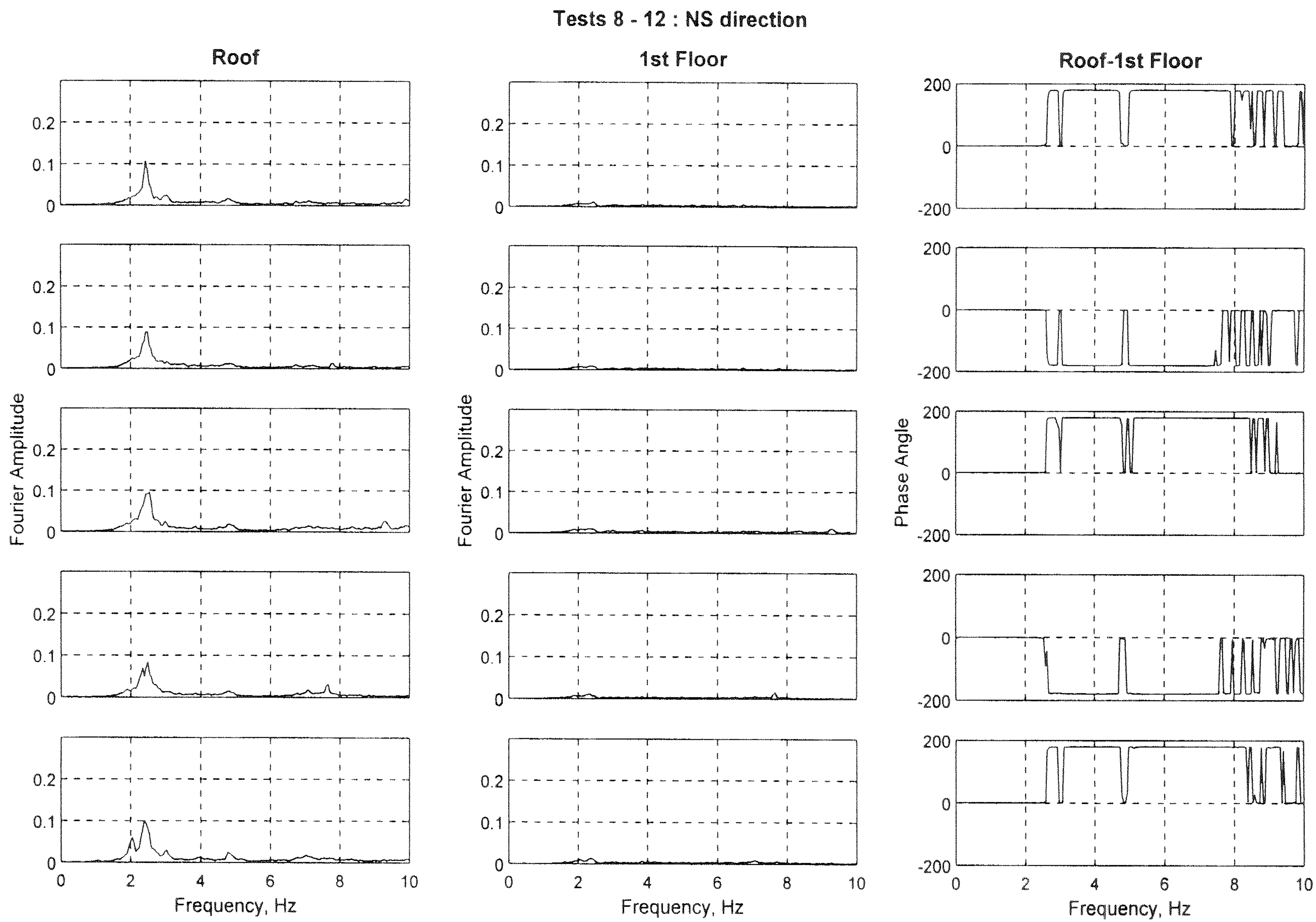


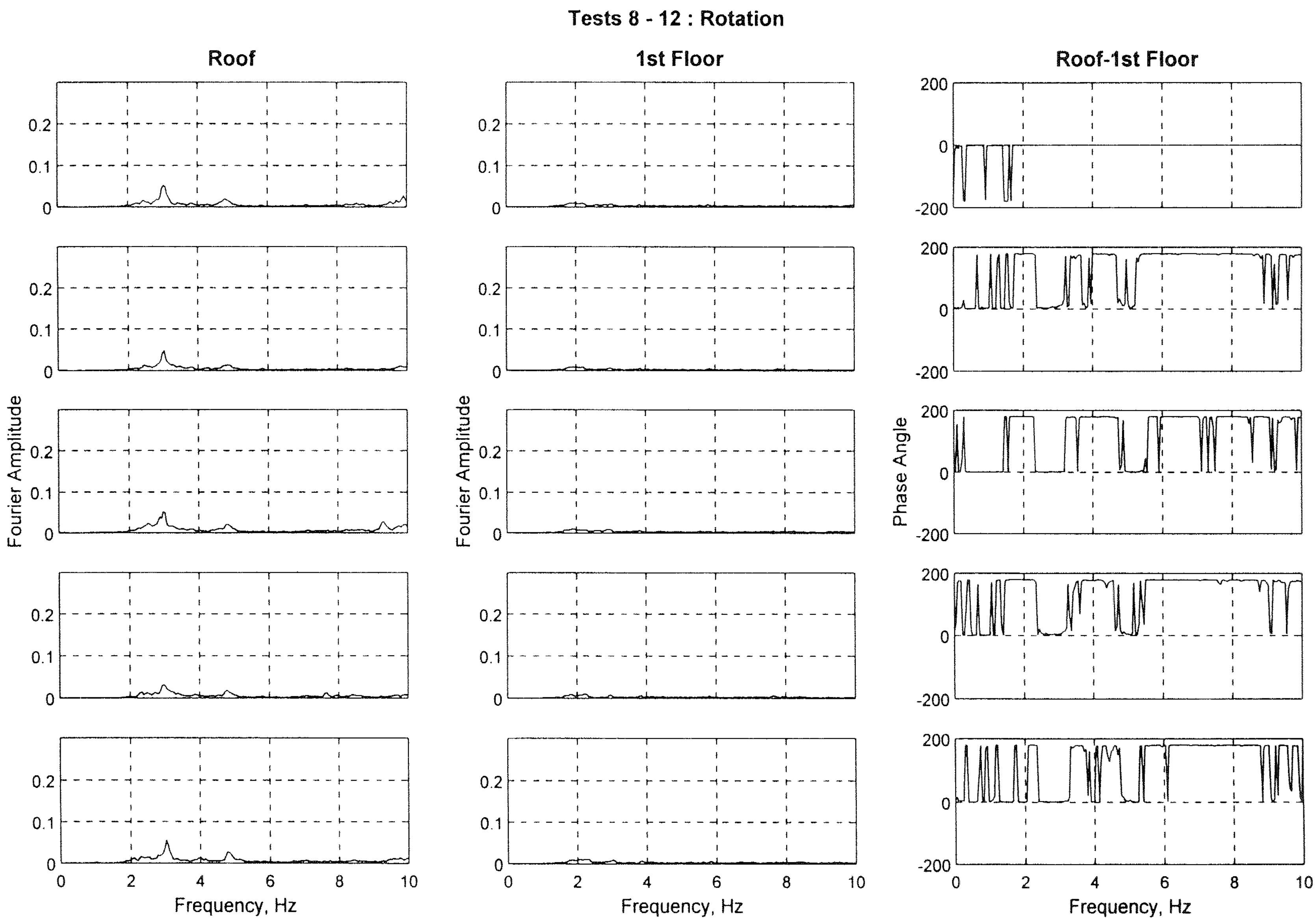
Tests 3 - 7 : NS direction

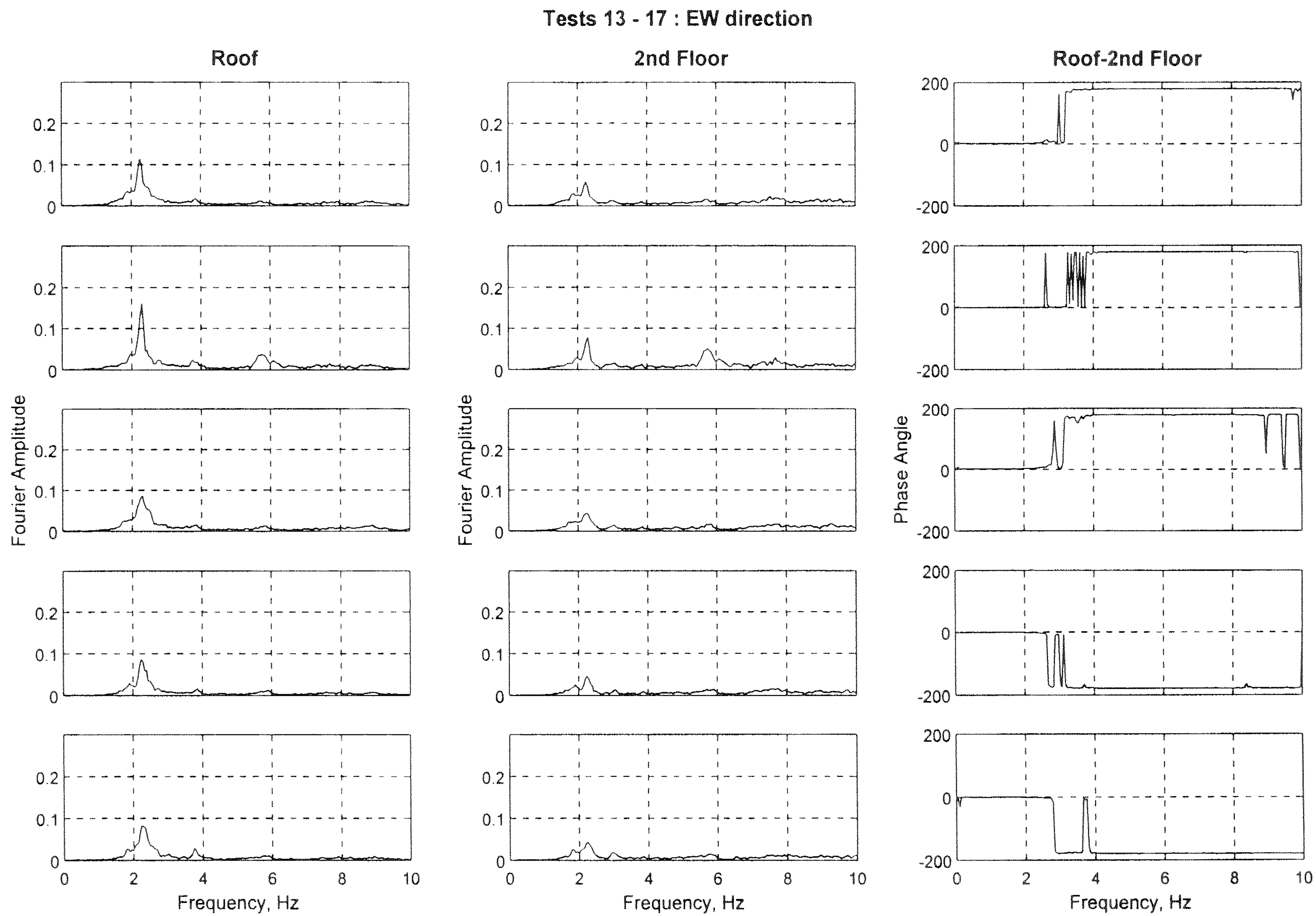



Tests 3 - 7 : Rotation
Roof
Basement
Roof-Basement
Fourier Amplitude
Phase Angle
Frequency, Hz
0
0.1
0.2
-200
200
2
4
6
8
10

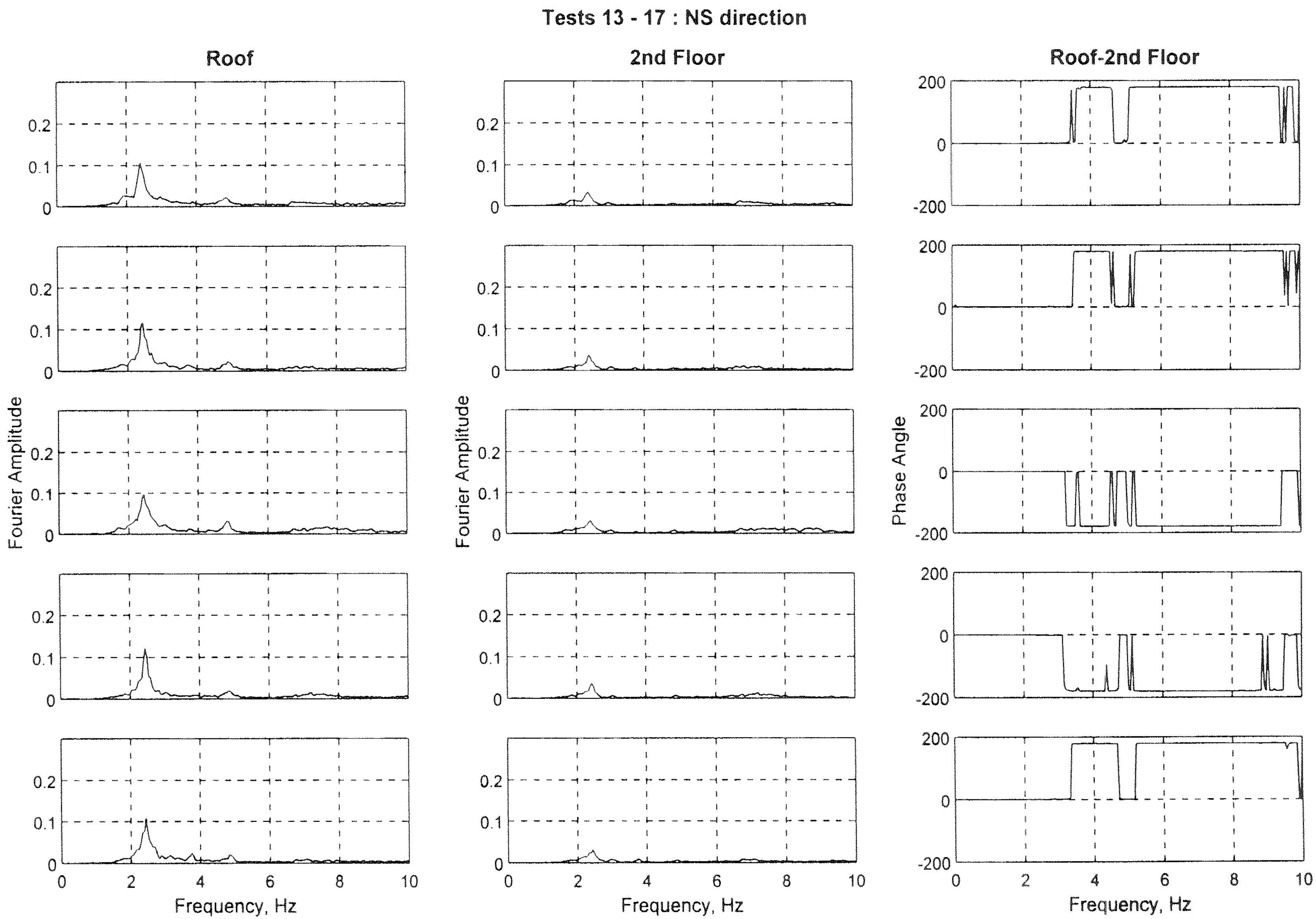

Tests 8 - 12 : EW direction
Roof
1st Floor
Roof-1st Floor
Fourier Amplitude
Phase Angle
Frequency, Hz
0.2
0.1
0
200
-200
2
4
6
8
10


Tests 8 - 12 : NS direction
Roof
1st Floor
Roof-1st Floor
Fourier Amplitude
Phase Angle
Frequency, Hz


Tests 8 - 12 : Rotation
Roof
1st Floor
Roof-1st Floor
Fourier Amplitude
Phase Angle
Frequency, Hz
0.2
0.1
0
200
-200
2
4
6
8
10

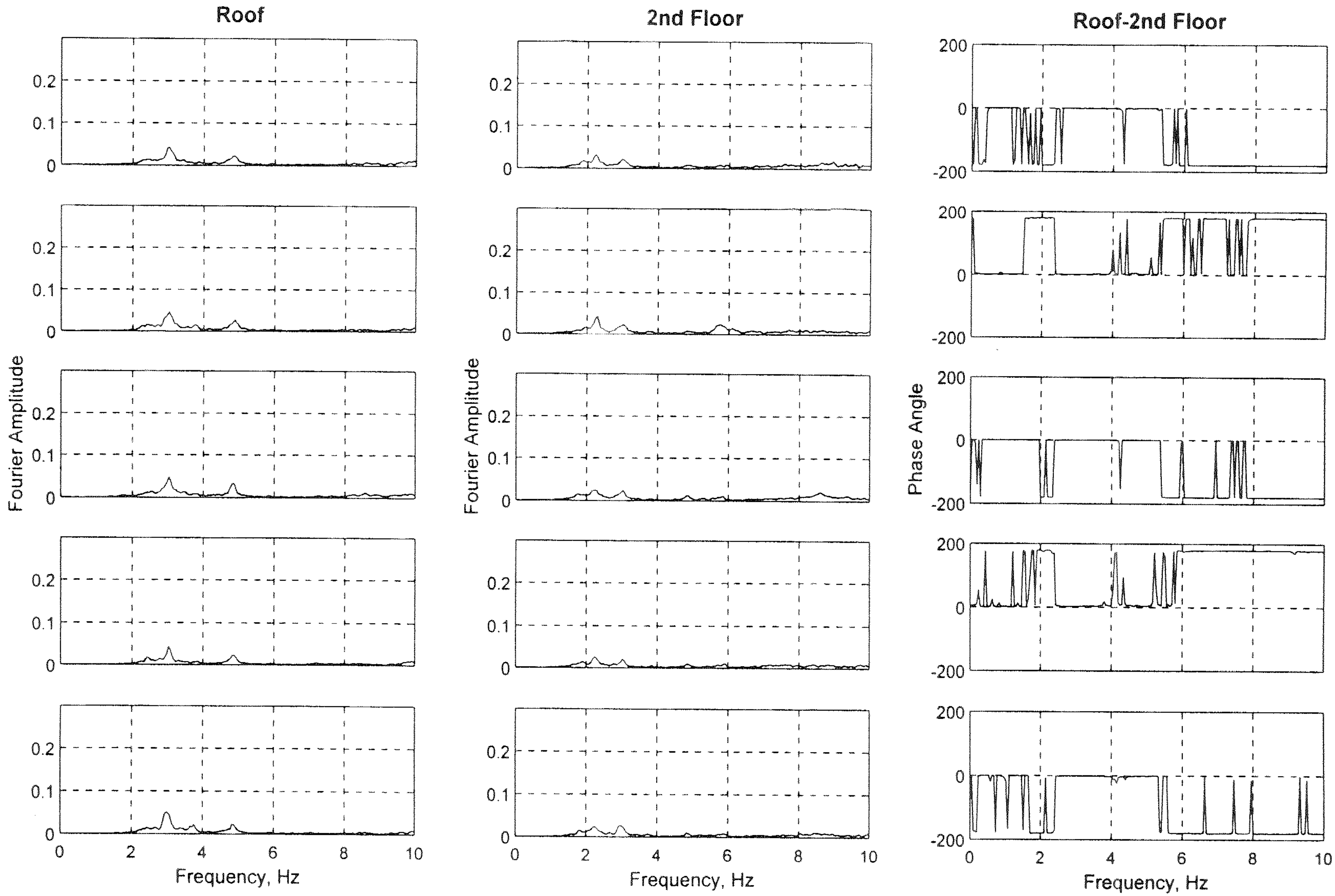


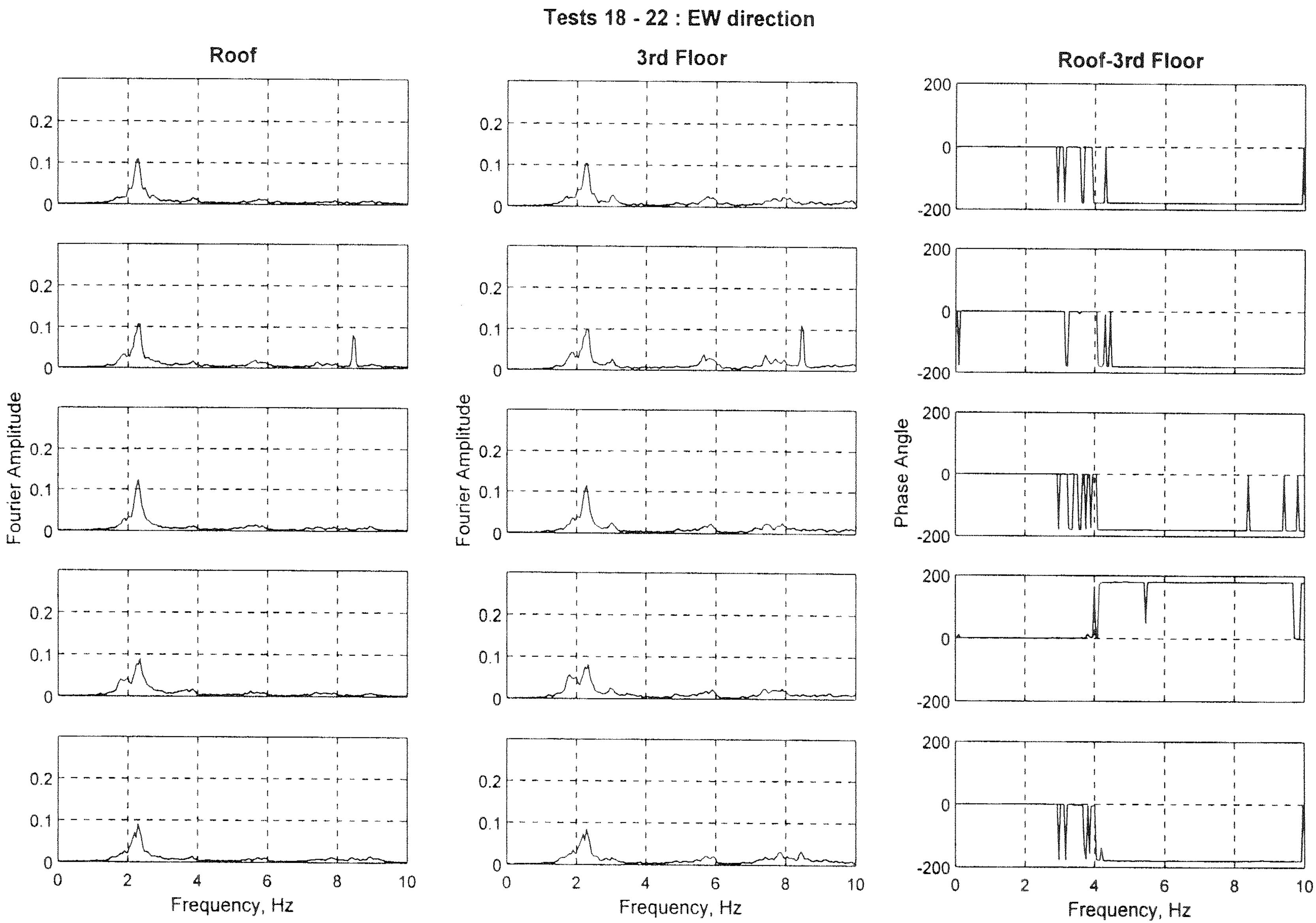
Tests 13 - 17 : EW direction
Roof
2nd Floor
Roof-2nd Floor
Fourier Amplitude
Phase Angle
Frequency, Hz



Tests 13 - 17 : NS direction
Roof
2nd Floor
Roof-2nd Floor
Fourier Amplitude
Phase Angle
Frequency, Hz

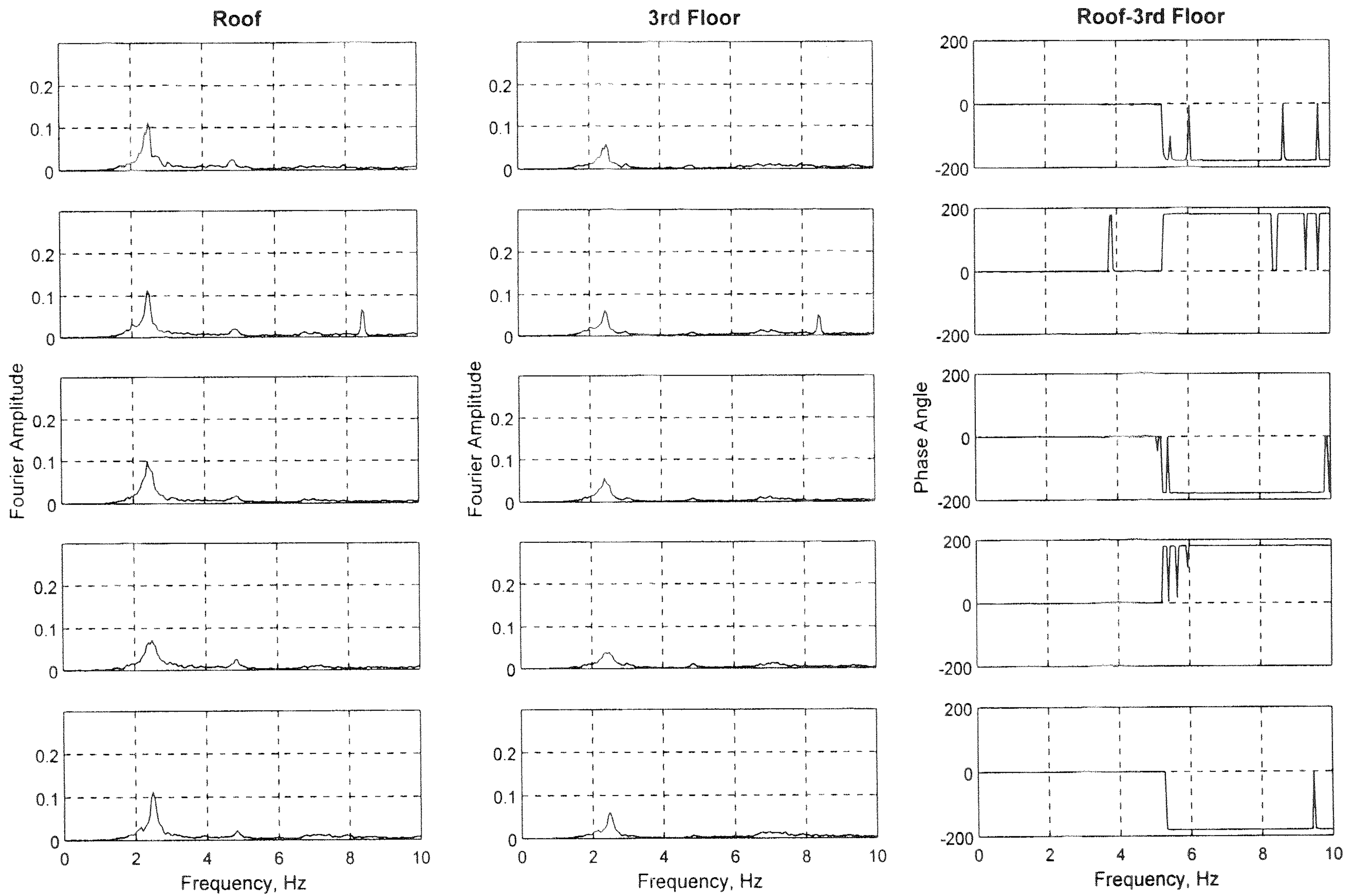
Tests 13 - 17 : Rotation



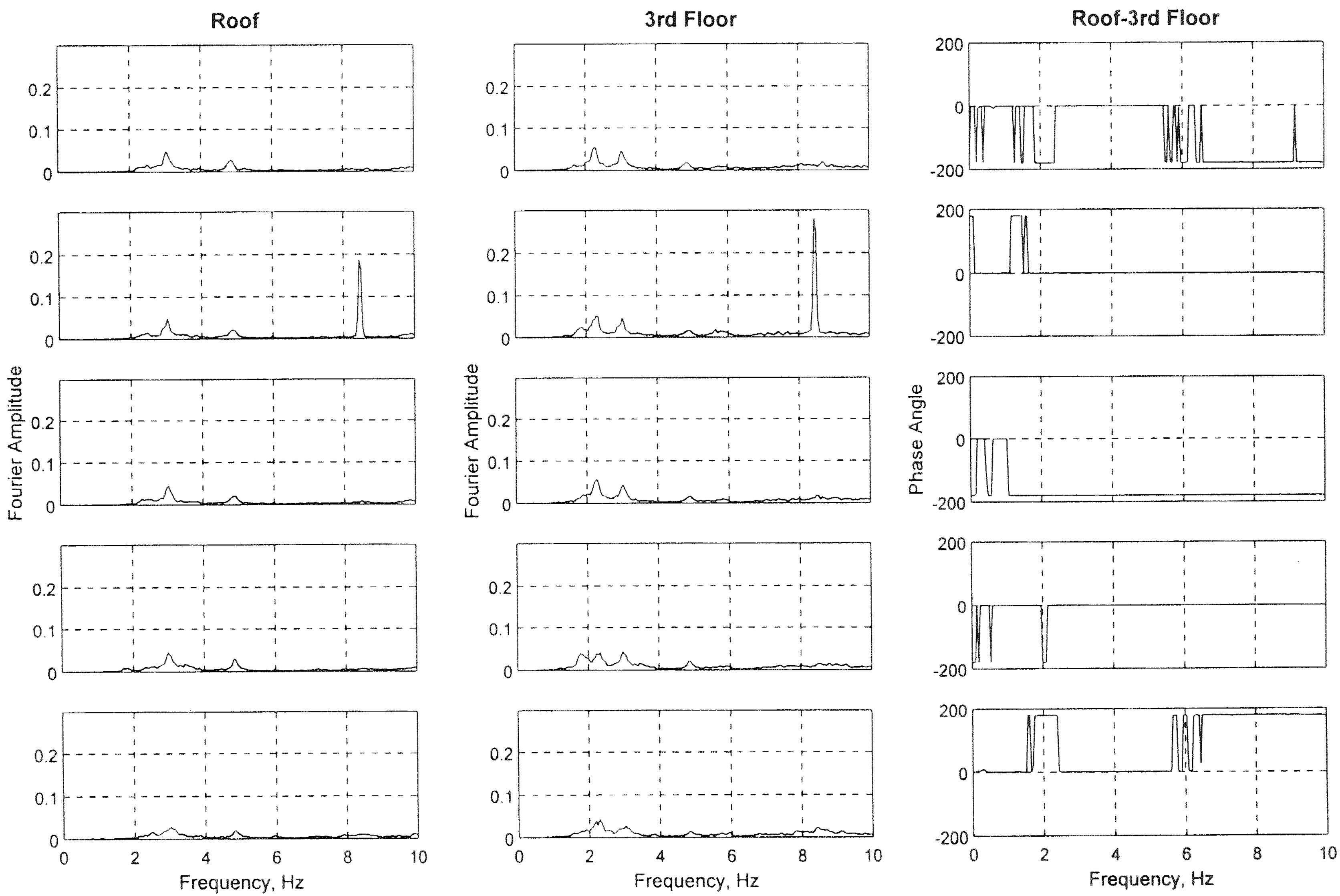


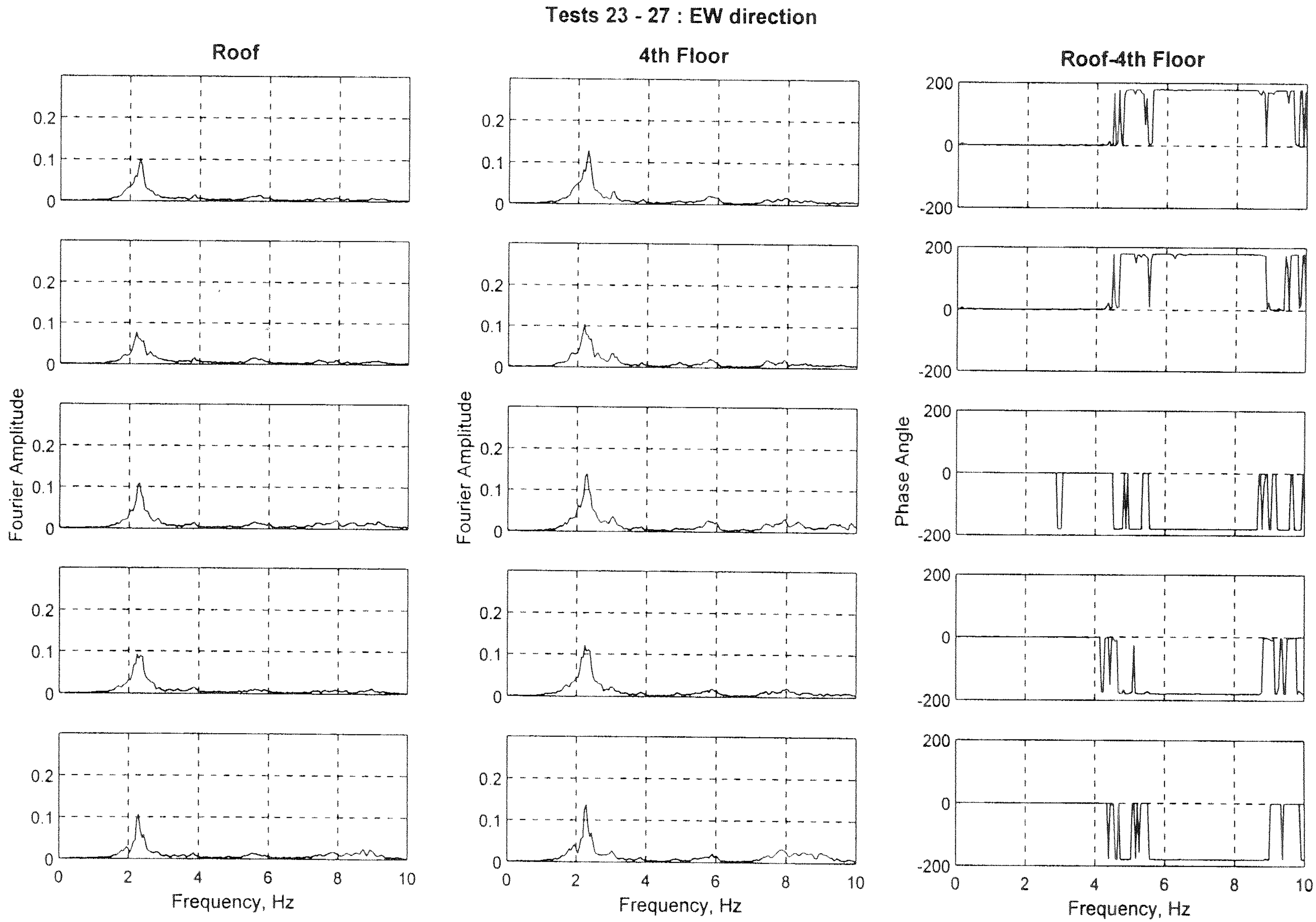
Tests 18 - 22 : EW direction
Roof
3rd Floor
Roof-3rd Floor
Fourier Amplitude
Phase Angle
Frequency, Hz
0
2
4
6
8
10
0.2
0.1
200
-200

Tests 18 - 22 : NS direction

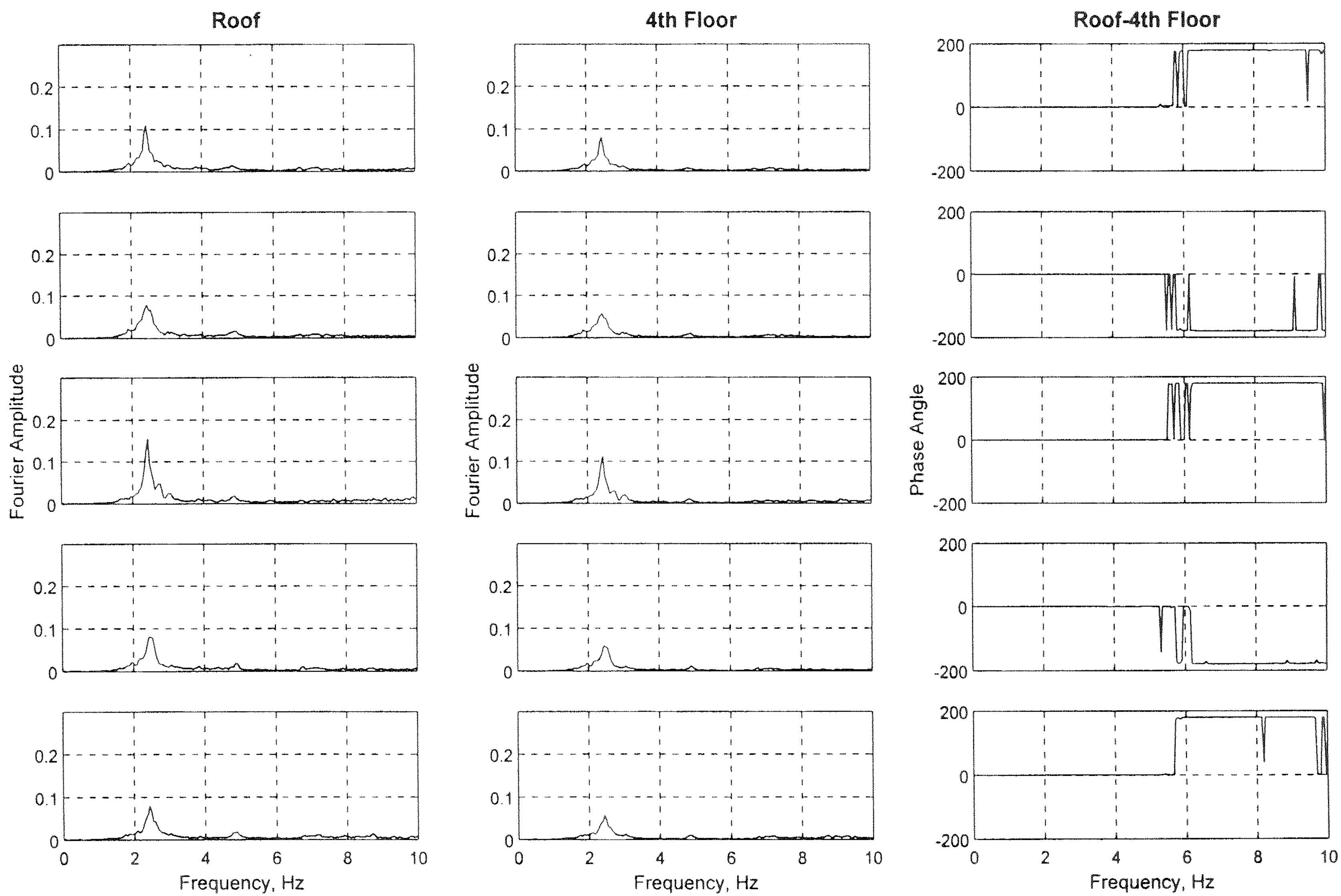


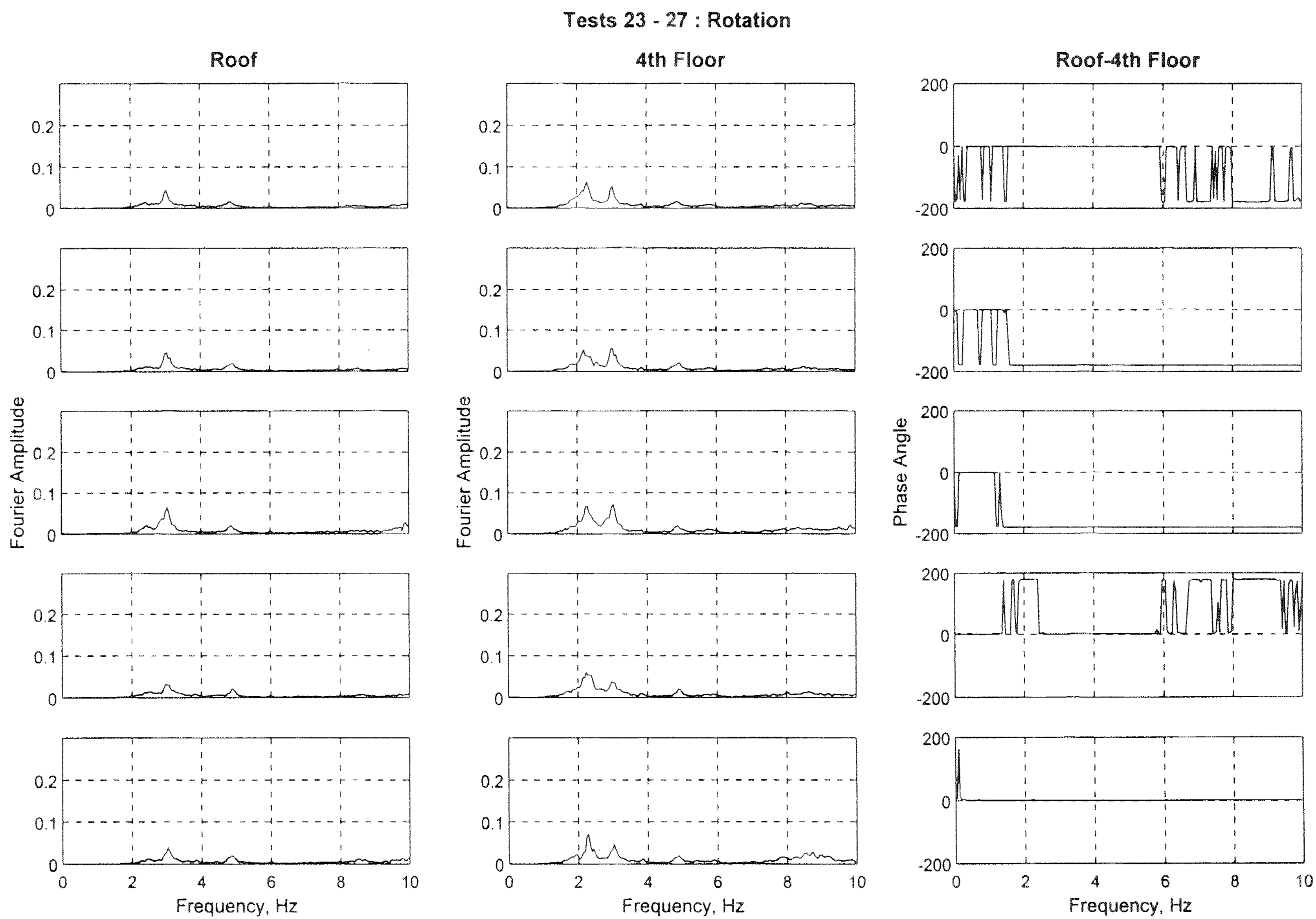
Tests 18 - 22 : Rotation



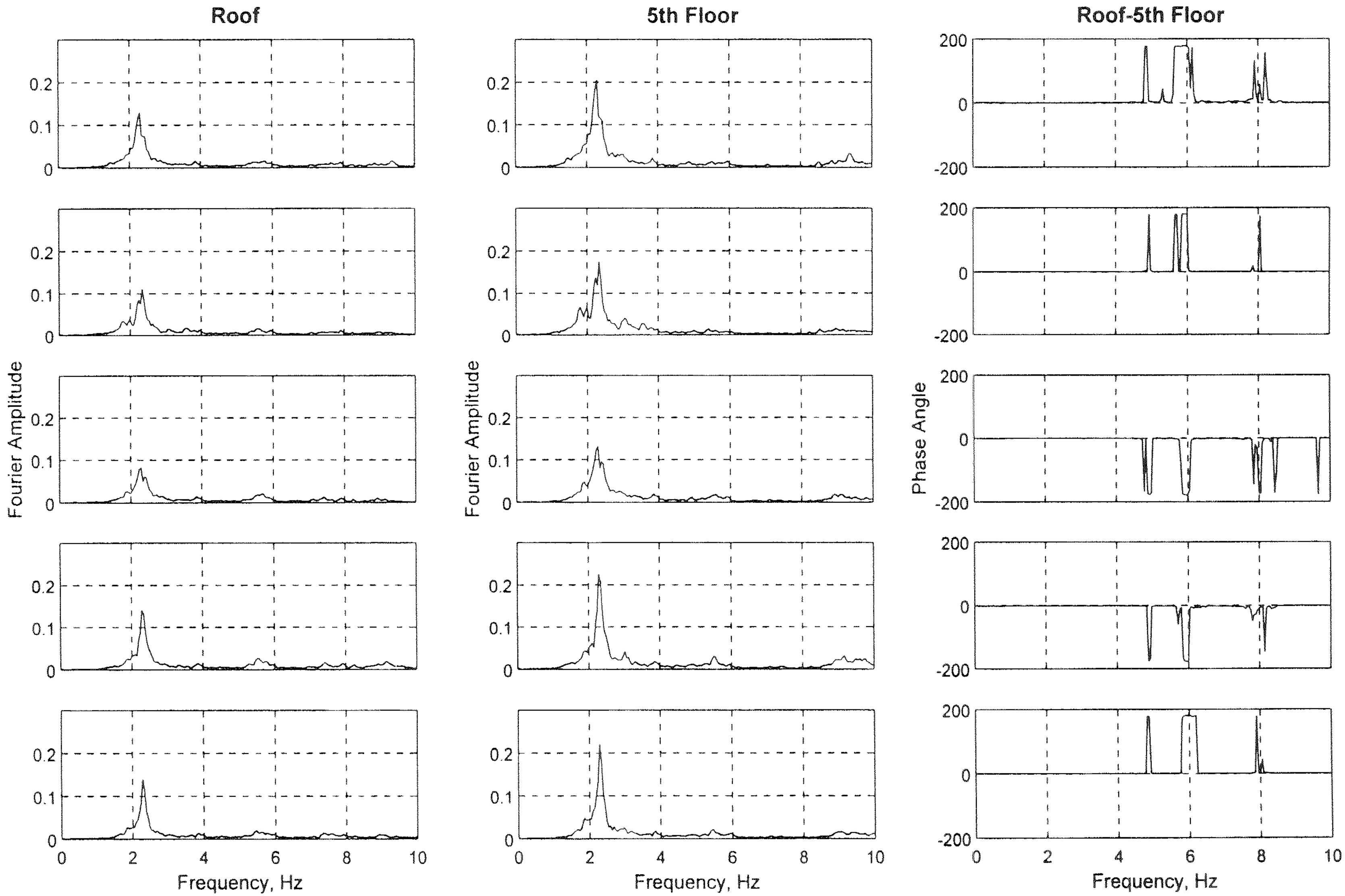

Tests 23 - 27 : EW direction
Roof
4th Floor
Roof-4th Floor
Fourier Amplitude
Phase Angle
Frequency, Hz

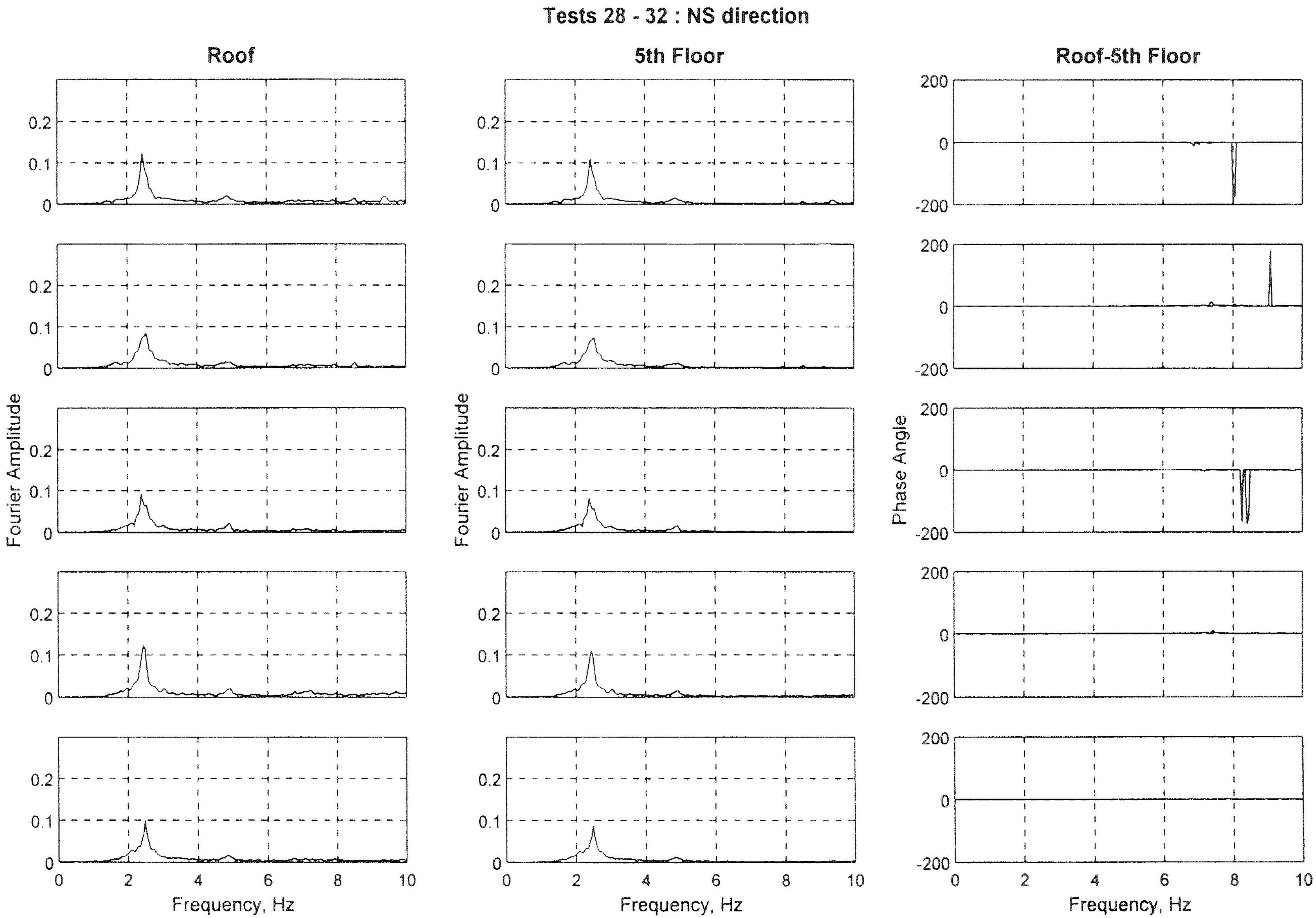
Tests 23 - 27 : NS direction




Tests 23 - 27 : Rotation
Roof
4th Floor
Roof-4th Floor
Fourier Amplitude
Phase Angle
Frequency, Hz
0.2
0.1
0
200
-200
2
4
6
8
10

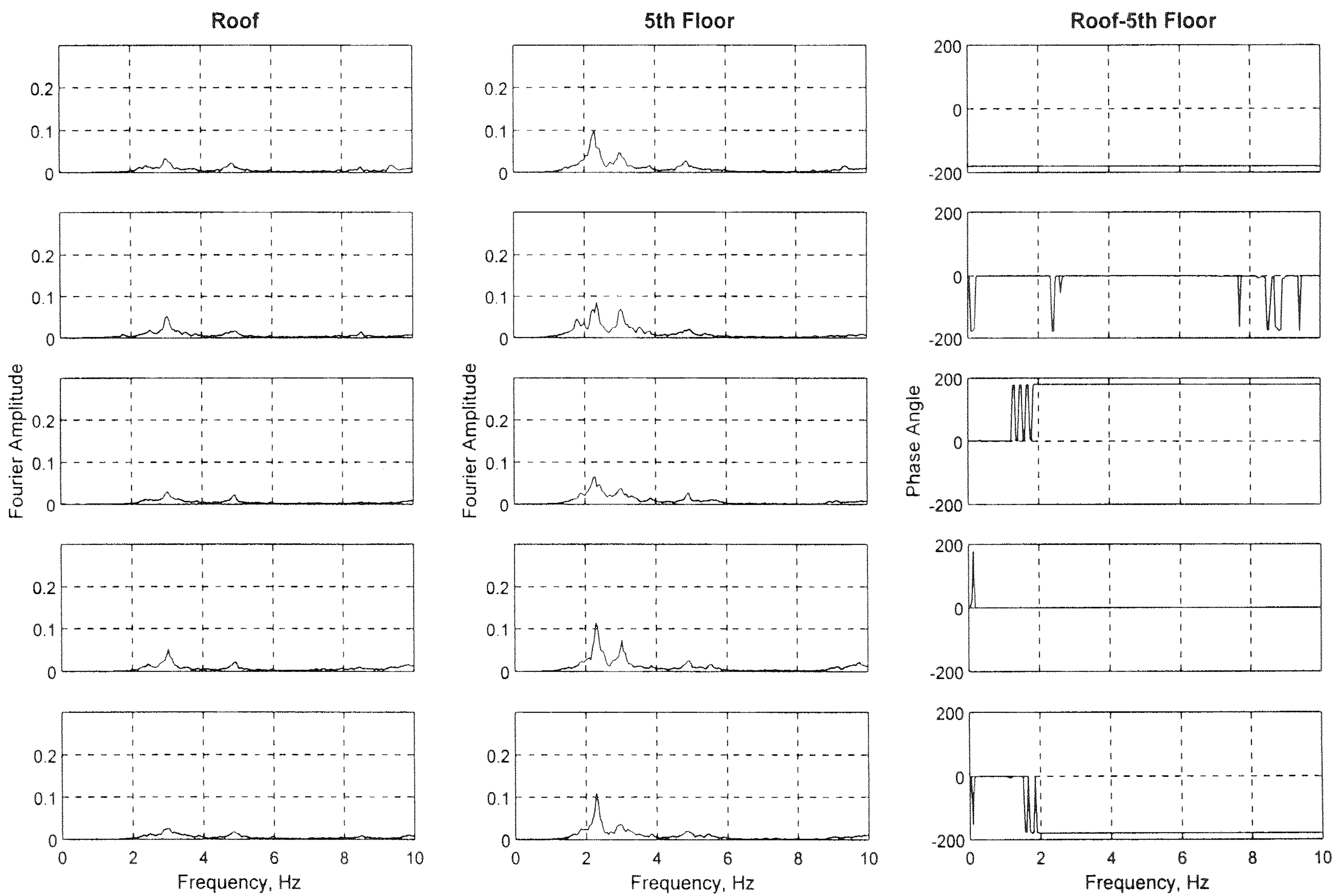
Tests 28 - 32 : EW direction



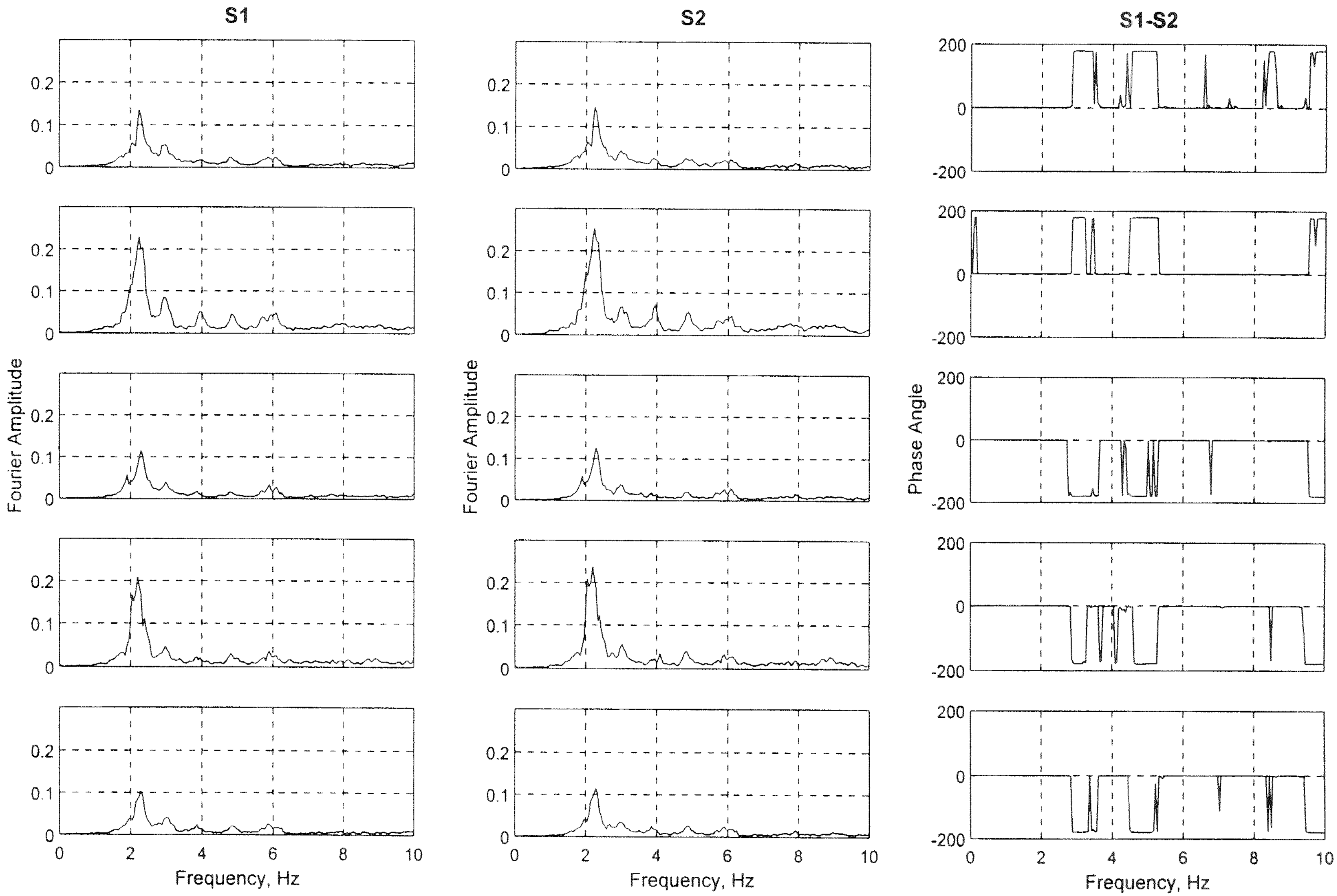


Tests 28 - 32 : NS direction
Roof
5th Floor
Roof-5th Floor
Fourier Amplitude
Phase Angle
Frequency, Hz

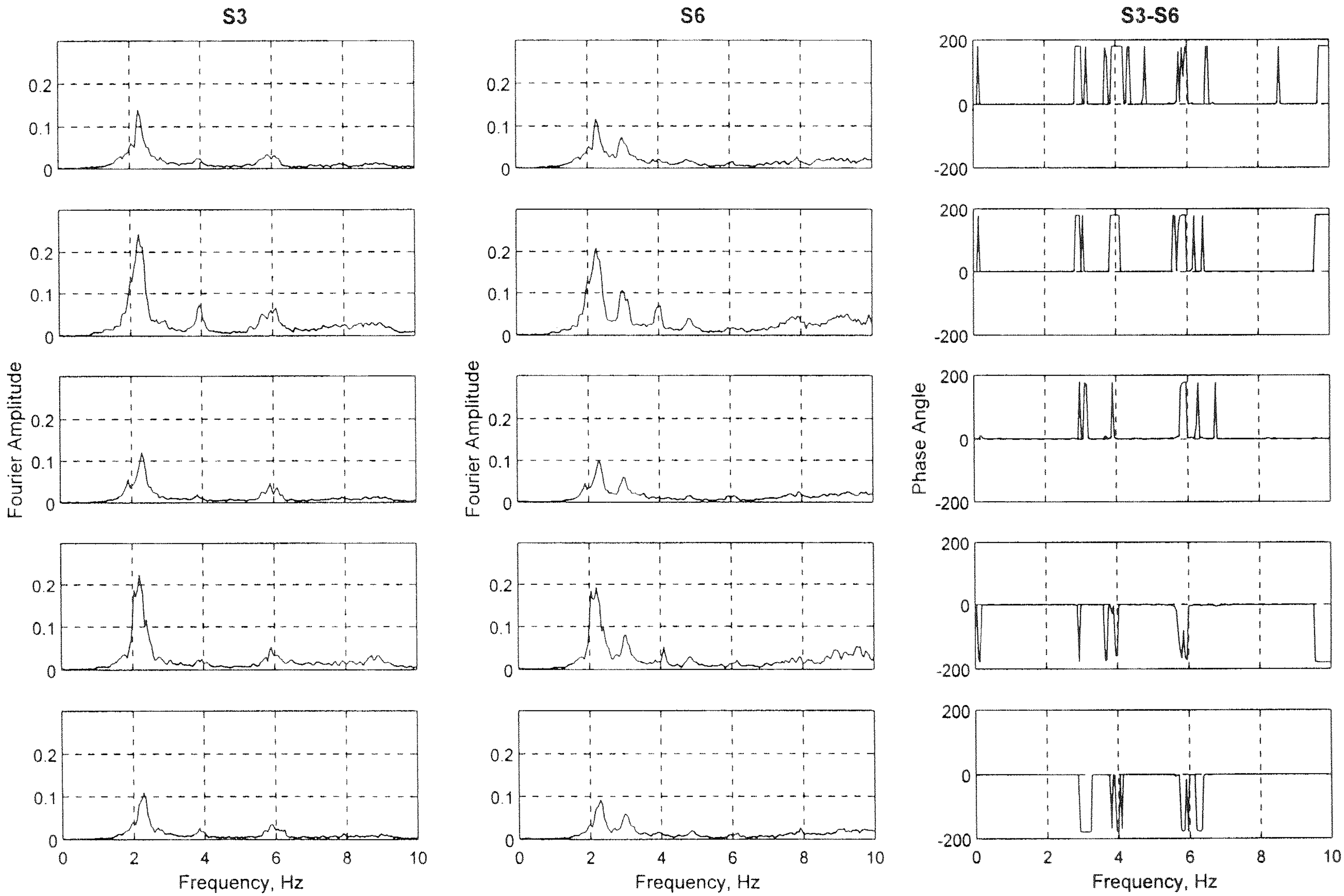
Tests 28 - 32 : Rotation

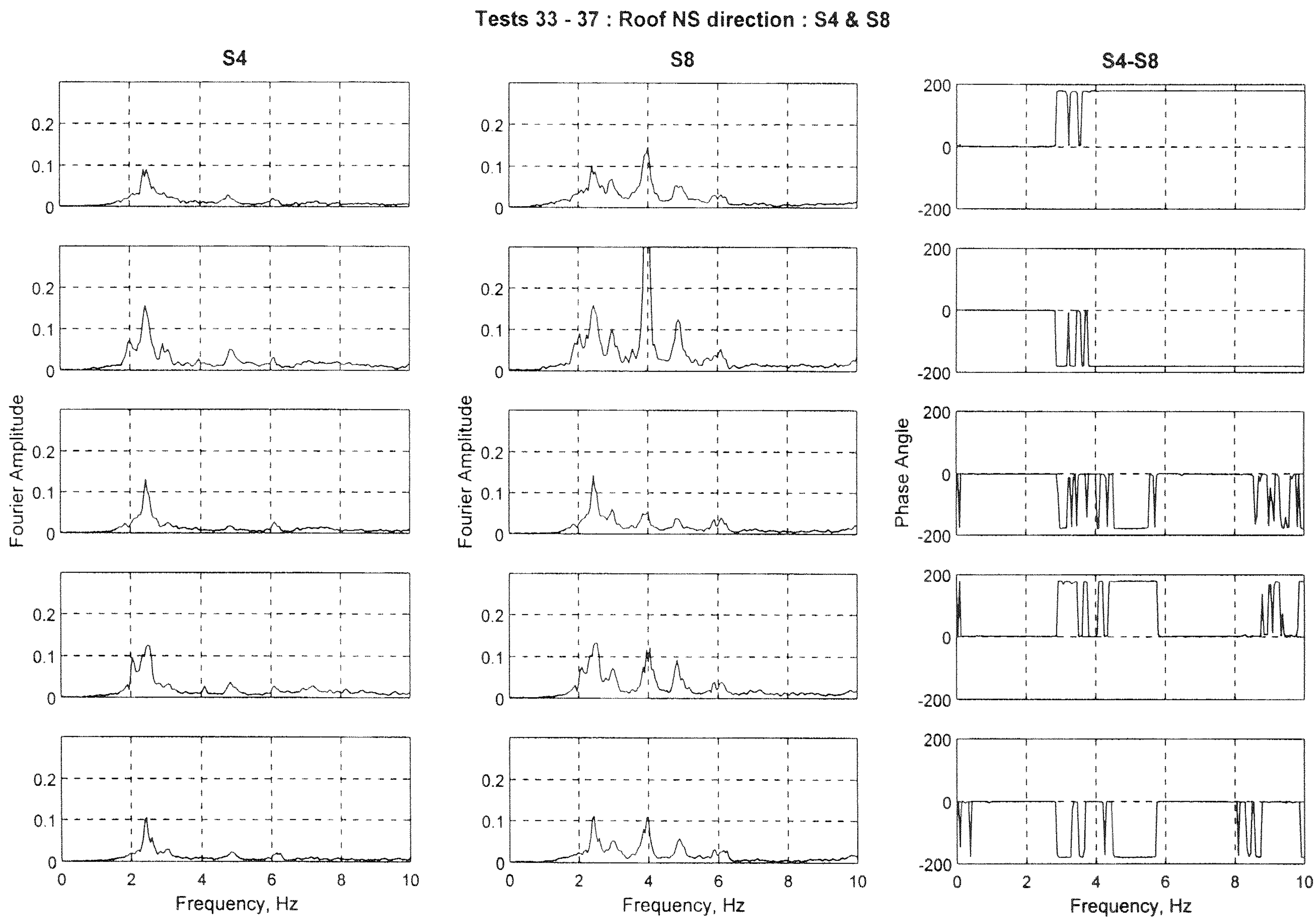


Tests 33 - 37 : Roof EW direction : S1 & S2



Tests 33 - 37 : Roof EW direction : S3 & S6




Tests 33 - 37 : Roof NS direction : S4 & S8
S4
S8
S4-S8
Fourier Amplitude
Phase Angle
Frequency, Hz